In this book Professor McAdie explains in non-technical language what has thus far been learned about the structure of the atmosphere and the conditions which cause changes in the weather—the basic facts which meteorologists use in making forecasts. He shows how great an influence the weather has had in the past on man's activities both in wartime and in peace, and he suggests that when scientists have acquired a thorough understanding of the physical processes of nature weather will be man's servant rather than his master.

MAN AND WEATHER

LONDON : HUMPHREY MILFORD

OXFORD UNIVERSITY PRESS

SKIRON THE NORTHWEST WIND

THE PREVAILING WIND IN THE UNITED STATES

MAN AND WEATHER

BY

ALEXANDER McADIE

Abbott Lawrence Rotch Professor of Meteorology, Harvard University and Director of the Blue Hill Observatory; formerly Professor of Meteorology, U. S. Weather Bureau; Senior Aerographic Officer U. S. N. R. F. Overseas, 1918

CAMBRIDGE

HARVARD UNIVERSITY PRESS

1926

PRINTED AT THE HARVARD UNIVERSITY PRESS
CAMBRIDGE, MASSACHUSETTS, U. S. A.

FOREWORD

THESE essays are essentially a series of lectures delivered in the Lowell Institute Course, December 1924.

They were intended to be popular and free from technical description and detail, and are now offered to a larger audience, as a slight contribution in awakening interest in the coming science — Aerography, the description of the atmosphere.

Some of us hopefully believe that in time there will be achieved a command of the air by men, rather than as now and heretofore command of men by the air.

A. M.

CONTENTS

MAN AND WEATHER

Chapter I

THE STRATEGY OF WEATHER IN WAR

THE march of the children of Israel across the shallows of the Red Sea was not exactly warfare, but it was essentially a test of national strength and a revolt against oppression's yoke, which throughout the centuries have been accomplished chiefly by resort to arms. We may then be permitted to regard it as a quasi-military action in which weather played a controlling part. What happened? We do not know; but presumably the Israelites were quick to take advantage of a temporary shoaling; and finding it possible to go ahead, proceeded to cross while yet the strong east wind was blowing. For such a wind, accompanied by high atmospheric pressure, drives back the waters and exposes the bottom lands. The Egyptians in heavy marching order pursued them, but as the wind shifted and the pressure fell, the waters came rolling back. Chariots, horses, and riders were speedily engulfed. If the Egyptians had had the services of competent forecasters and modern methods,

they probably would have been warned of the impending wind shift.

The incident illustrates the truth of the observation that next to being able to control the weather, the best thing is to know enough to take advantage of weather conditions.

A more striking instance from ancient history is the defeat of the German tribes by Marcus Aurelius Antoninus in the year 174. The Romans were hard pressed, practically hemmed in, and suffering from lack of water. A sudden and severe thunderstorm not only frightened the Quadi, but gave the needed rain — and ultimate victory. And so through the years to come those warriors were to be known as the Thundering Legion.

Very different, but yet with results determined in large measure by weather, was the experience of the Invincible Armada. At the end of July 1588, the Spanish fleet had not succeeded in reaching the ports for which it was headed, in order to transport the Spanish army then blockaded by the sturdy Sea Beggars of Nassau. So the great fleet abandoned the project, and placing safety first headed north, shaping a course around Scotland. If August had been a normal late summer month, the stately galleons would probably have

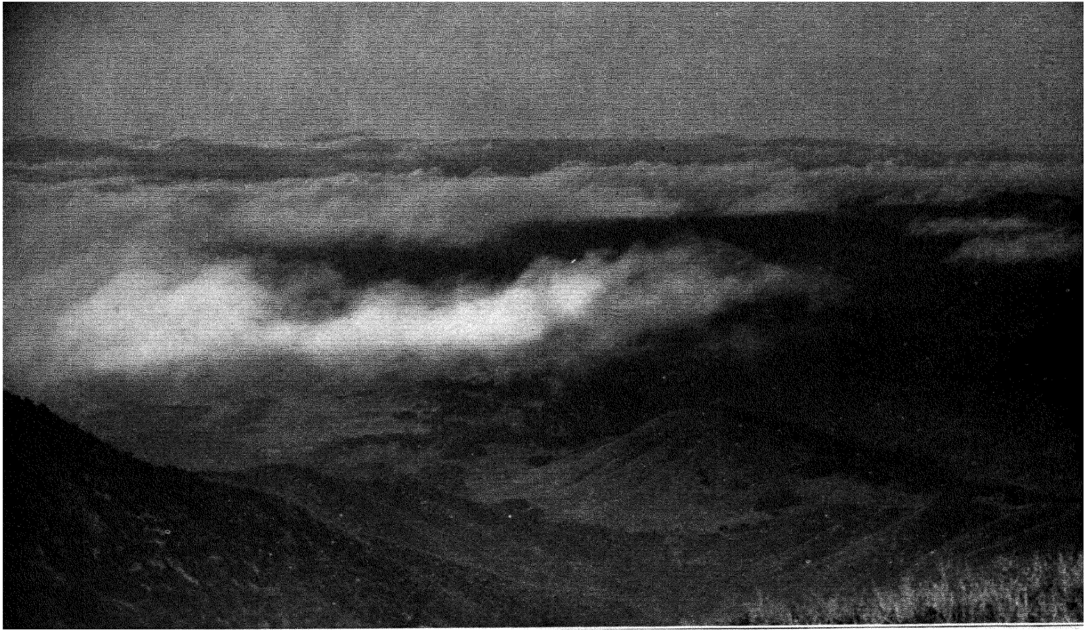
made sufficient northing, then steered west and south and hence in safety to the home ports. But the late summer of 1588 was marked by a succession of storms from the Atlantic, strong northeast winds changing quickly to northwest gales; and the worn and hapless soldiers — never much as seamen — fought an unequal fight. Ship after ship left its bones on the rugged coasts of Scotland and Ireland. Meanwhile Queen Bess, riding her pony to the camp at Tilbury, where were gathered her men-at-arms mobilized for defense against the Duke of Parma's veterans, made an inspiring address. But she might have said to the troops — with truth:

> You can go home now; there will be no invasion! The weather has fought for us!

Let us pass over two centuries, during which the nations of Europe quarreled and warred over boundaries at home and new possessions overseas. The greatest of these colonial wars was in progress, not as nation against nation, but as a war for independence — the colony fighting the homeland. In August 1776, the Battle of Long Island was fought between the armies of Howe and Washington. The continental troops were defeated. Worse still, a

British fleet was in the East River cutting off retreat. The trap had been sprung and apparently the rebellious army was caught. That night, August 29, was foggy. The fog was dense. An aerographer would say there was a marked inversion. The air was cool near the ground and quite warm fifty or a hundred feet higher. This makes the low, dense white fog, which not infrequently covers the rivers of this section after midnight and does not dissipate until nine or ten o'clock on the following morning. In the silence the American army slipped across to New York. Nor could the lookouts on the British warships see or tell their whereabouts. What would have happened but for the friendly fog?

The incident should not be passed over lightly by historians, for there was more at stake than the escape of a beaten army. The success of the war for Independence was not all; for the struggle essentially determined the more important problem — the right of colonists to govern themselves. The lesson then learned by the Mother Country — the greatest of colonizers — meant toleration and recognition of rights throughout that loosely constructed but firm-holding empire, on which the sun never sets.



MORNING FOG IN THE VALLEYS

Twenty years after American independence had been established the nations of Europe were still busy with war problems arising from unholy ambitions to acquire neighboring territory. A French general, one who later would proclaim himself an emperor, found it necessary to hurry back to France from Egypt. He had to cross the Mediterranean in a sailing ship. The trip to-day could be made by airplane. A British admiral, who later was to defeat French fleets and win for himself a high place in the affection of his countrymen, was patrolling the Mediterranean. The ship which carried Napoleon passed near the warship which Nelson commanded, but owing to the fog escaped detection and capture. Much of the warfare which devastated Europe from 1801 to 1815 might have been avoided if Napoleon had then been captured.

While the weather favored Napoleon in these earlier years it was to turn against him later. He began his Russian campaign with an army of 450,000 men. Before five months had elapsed that army was in headlong flight — the Emperor leading, nor pausing even to encourage the handful of veterans fighting rear-guard actions under Ney. Swift as fast horses could carry him, he sped on to Paris. From

June to December 1812, Napoleon fought the weather; and what had once been a *Grande Armée* dwindled to a miserable band of ragged, famished men.

There is a still later experience in Napoleon's career connected with weather.

Victor Hugo wrote in *Les Misérables:*

> If it had not rained on the night of June 17, 1815, the future of Europe would have been changed. A few drops of rain mastered Napoleon. Because Waterloo was the finale of Austerlitz, Providence needed only a cloud crossing the sky out of season to cause the collapse of a world.

There were heavy thunderstorms on the 16th and 17th and the movements of the French scheduled for early hours on the 18th were delayed until near noon because of bad roads. And time was of the utmost importance to the French.

It is a far call from Waterloo to the battles of our Civil War; and we mention the latter only because it has been seriously claimed that in these battles cannonading caused precipitation. This is not the strategy of weather in war but the reverse — the control of weather by war. In Edward Powers' book, "War and Weather" (1890), he cites action after action which it is claimed produced rain, or rather

was followed by rain. Unfortunately for the theory, there is no evidence that the rains mentioned were not natural rains, which would have occurred regardless of firing. The book, in large measure, was responsible for the action of Congress in 1891, when it appropriated $10,000, of which $9,000 were spent in bombarding the clouds without tangible results.

Since then there has been an unending succession of rainmakers. There is, however, no scientific basis for the belief that concussion can produce rain, and the claims of the rainmakers generally are unfounded. During the World War, there were numerous instances of heavy firing not followed by rain, and on the other hand, the heaviest rains were recorded during quiet periods — naturally so, as rain makes mud, and armies can not very well move forward at such times. The true strategy of weather in war is to be able to foresee frequent heavy rain; also periods of exhausting heat or benumbing cold.

We come then to the events of the World War. No nation is now without an Air Service, and no Air Service is without its forecasting branch. The decisive battles of future wars will be fought not on land or on sea, but in the

air. The first lines of offence and defence will be the squadrons of the air. The strategics of war will be changed and individual units count for less, while *weather* will count for more.

Aerography is the youngest of the three sister sciences in geo-physics, viz.: geography, hydrography and aerography. All may claim that they are in truth the sciences which tell of life's adjustment; for all three have to deal with man's efforts to rise superior to environment.

The campaigns of the future must take into account operations on land, on and in the sea, and *in the air*.

In the late great struggle and resort to force, Germany first clearly recognized the importance of a thorough knowledge of air structure. Then France, Great Britain, Italy and finally the United States awoke to the need of efficient weather service; and by coöperation such a service was maintained during the last year of the struggle, and rendered good service, especially in connection with the protection of aviators.

In the World War we became familiar with air raids. Their deadliness and efficiency were fully recognized as the war ended. While the actual damage done was considerable and the

moral effect great, both were small compared with what would happen to-day, when the size of bombs is tenfold larger, and deadly gas bombs as well as high explosives can be dropped. Weather will control offensive operations more than ever.

The raid of October 19, 1917, will serve as an illustration of the strategy of weather in war. An air fleet of thirteen raiders started Thursday night as the new moon was setting. The German weather forecasters gave the word to start as conditions favored a high pressure over Northwestern Europe, and light surface winds. Here is the direct application of aerography to a military offensive. The German forecasters, however, did not have full information from the west, and although clever, they did not know all the factors. It seemed like the right time to make an attack through the air upon the unprotected manufacturing centers of Great Britain. And the battleships of the Grand Fleet and the lighter naval forces of the Channel Patrol were alike powerless to stop a raid by Zeppelins.

The wind over the plains of Flanders and the southern part of England was from the southwest, and light. Of eleven airships, a splendid fleet, nine reached the outskirts of London and one passed directly over the city.

At the surface the wind was light and favorable; at 1000 meters, from the west and of moderate velocity; at 5000 meters the wind was northwest, strong and increasing. All would have gone well with the invaders if the weather had remained settled. But a depression developed in the Atlantic, west of the British Isles, and the light variable winds, characteristic of settled fair weather, were routed quickly by cold north or northeast winds of twenty meters or more per second. The airships from midnight until 7 A.M. were carried south and somewhat east, at a speed of fifty miles an hour. The raiders supposed they were 350 kilometers east of London and Holland, when in fact they were 600 kilometers southeast of London and so over the French lines. The surface fog which would have dissipated two hours later, prevented recognition of the territory below. As they came earthward, the noise of the engines was heard, and their presence detected by the enemy. French airmen quickly completed what frozen radio motors, increasing north wind and bitter cold had begun, and demoralized the raiders. Some of the ships were shot down; one escaped westward but fell into the sea. The flagship intact fell into the hands of the enemy as the captain

McAdie

A BILLOW OF FOG

of the ship hesitated too long in firing the explosive bullet. The Invincible Armada of the Air had met with a sorry fate; and incidentally *Germany lost her supremacy in the air.*

We come next to the attempt to force the Dardanelles, or we may call it the Twentieth Century Siege of Troy. The siege that Homer wrote of lasted ten years, while this later siege lasted only eight months; but that was long enough, for in that time the killed, wounded and missing, on the side of the Allies, numbered 150,000; while the Turks lost probably 300,000.

Whoever conceived the idea of forcing the Dardanelles was a brilliant strategist. Constantinople was unquestionably the vulnerable point, and its capture would have ended the war just three years earlier; and incidentally the peace which would have followed would have been more effective for good.

In February 1915, the British Fleet tried to run past the forts. The essential factor of success was surprise. The Turks were taken unawares and off guard, the bombardment was effective and success was within reach, when the weather changed. Southwest gales forced the ships to run for safety to the open sea. The hour passed, never to return. Ten thousand

men landed then could have taken and held the heights, which later a hundred thousand could not hold. There followed another bombardment, but the Turks were prepared and floating mines and submarines were more than a match for the largest battleships.

During the summer months the Etesians — searching hot winds, making life miserable for man and beast — blew with their accustomed force, and throughout August the weather fought the battle for the Turks. Then from extreme heat to extreme cold. There was a blizzard in November that raged for three days, and when it was over, thirty thousand men were incapacitated. Evacuation was inevitable, and in all history there can be found no retreat more ably handled than this withdrawal from Helles. On the night of January 8 the last foothold was relinquished, and not an hour too soon, for a southeast gale swept the coast on the following morning; and disastrous as the whole campaign had been, these gallant souls were spared a final and overwhelming catastrophe.

We come now to what should have been the climax of the World War — the greatest battle in history and the most momentous; instead of which it was indecisive and somewhat

of a puzzle. Early on the afternoon of May 31, 1916, Admiral Sir David Beatty, with the battle cruisers of the British Navy, received word from the scout ship Galatea that the enemy, the German High Seas Fleet, was out in force. Remember that for twenty-two long months the Grand Fleet of Britain and the High Seas Fleet of Germany, the heavy-weight champions of the war, had been preparing for a meeting in the North Sea, and the outcome of that fight would end the war. For if the British fleet won, the weapon which Germany had been forging for years would be destroyed and her sea-power gone, while on the other hand, if the German fleet won — and everything that human ingenuity could devise had been done to assure them of victory — then the main offensive weapon of the British Empire would find its grave in the North Sea, and Germany, mistress of the seas, could easily have prevented supplies and reinforcements from overseas, and thus quickly have brought the war to a triumphant finish. In fact, the fate of the British Empire was at stake.

The battle cruisers had the difficult work of engaging and holding, if possible, the German fleet, until the heavier ships — the main portion of the British sea force, then sixty-five

miles to the north, under Admiral Jellicoe — could rush southward.

At four o'clock firing began across a ten-mile gap. The Germans, having better range-finders and showing superior marksmanship, soon punished the battle cruisers for their temerity.

The British were also handicapped by poor visibility, haze and smoke combining to prevent good marksmanship. At half-past six the British battleships arrived and soon engaged the enemy. At seven the visibility improved but enemy destroyers were throwing out smoke screens. So the battle raged with great uncertainty as to the outcome. Later the German fire slackened and while there was much confusion it appeared that the German ships were drawing out of action. The German admiral had indeed ordered a change of direction of one hundred and eighty degrees. He had executed a *gefechtskehrtwendung*, that is, a complete turn about. He disappeared in the fog at eight o'clock. The battle was then virtually over, although apparently the British command did not fully realize what the German admiral was doing. There were further manœuvres by the German fleet, which three times changed direction, not merely a few degrees, but complete turns, eventually working backward to its base.

The British were unable to locate the enemy in the dark; and moreover, disposition had to be made for the night and with the view of protection against torpedoes and submarines.

Morning broke early, with the Grand Fleet holding its position and ready for a renewal of the fight, but the German admiral had slipped away homeward to claim a great victory. The losses were heavy on both sides, notwithstanding that the great battleships never came to grips. The smaller vessels suffered most. In the Grand Fleet proper, only one life was lost, but on battle cruisers, destroyers and torpedo boats, on both sides, many were killed. The British lost 6,097, the Germans 2,445. In all, 8,542 officers and men went down, a small fraction, however, of what the loss would have been had the battleships arrived earlier. The losses were: battle cruisers *Indefatigable* (1017), *Invincible* (1021), *Queen Mary* (1263), *Black Prince* (862), *Defense* (913); destroyers *Tipperary* (186), *Shark* (86), *Turbulent* (85). The Germans lost one battleship, *Pommern* (840), and the battle cruisers *Wiesbaden* (570) and *Derfflinger* (?).

The determining factor in all four phases of the battle was low visibility due to mists, fog and smoke.

King George, addressing the assembled British captains a few days after the battle, told them that *weather* had deprived them of a well-earned victory.

It was not, however, weather at its worst in the North Sea; but such as it was, — the baffling mists of a summer evening, — it changed what might have been the greatest fight in history into an uncertain, indecisive action.

One last striking illustration of momentous consequences following an inaccurate forecast, or rather the absence of a reliable forecast, occurred June 5, 1916.

Field Marshal Lord Kitchener had hurried north on an urgent request from the Czar of Russia to visit St. Petersburg with a view to securing closer coöperation between the Russian forces and those of Western Europe. Kitchener arrived in Scapa Flow in the afternoon, dined with the Senior Officers and expressed himself as anxious to be off and on his way as soon as possible. A fast cruiser, the Hampshire, was detailed to carry him and his personal staff to Archangel. A heavy northeast gale was blowing. The naval officers there present were of opinion that the ship would make easier weather by proceeding out the west en-

trance and thus to some degree be sheltered from the northeast winds and high seas. The forecaster in London, had he been consulted, in all probability would have warned against such action, for the storm center was even then passing; and the northeast winds quickly changed to northwest winds of even greater velocity. The Hampshire started at five o'clock and about seven-forty struck a submerged mine which had been placed there a day earlier. The sea was rough, the winds high, and no help could be sent. The ship sank with crew and passengers. Only twelve of the ship's company survived. Kitchener was last seen standing by the captain as the vessel plunged.

Chapter II

WEATHER IN PEACE

THE importance of a knowledge of impending weather is now quite generally conceded in every line of human activity. There is no phase of existence which is not in some degree subject to modification by weather. Yet it was written of old

> He that regardeth the clouds shall not reap,

meaning that the man or woman who watched the skies intently would not acquire a surplus of this world's goods. In fact, he or she would get little of the so-called substantial things of life.

Yet it can easily be shown that the whole structure of society rests upon rain in due season; and without clouds, there can be no rain. It is evident that if there is no rain there will be no crops, and without these, there will be no need for farmers; and without farmers, there will be no food; and without food, well — it is plain, there will be no taxes; and without

FAIR WEATHER CIRRUS

taxes, government must cease, for a government cannot exist without money.

Imagine what an advantage one would have had who on the last day of February, 1915, could have definitely stated:

> The following month will be practically rainless in New England; and with less than a third of the normal along the Atlantic Coast north of Hatteras.

Or who at the end of September, 1913, could have made a forecast of an opposite character, namely,

> October will be a month of almost continuous rain with northeast winds and no warm spells.

Or if one lived on the Pacific Coast instead of the Atlantic, he could have said near the end of 1924:

> The dry period will continue in California, especially in the southern portion.

Or, venturing across the Atlantic, what fame would have come to the forecaster in London who boldly proclaimed at the close of the year 1920, that the coming year 1921 would be the driest year on record? It was indeed a memorable drought. In a land where summer showers are the rule, week after week passed with cloudless skies. Trees and shrubs

flowered for the second time late in October. For pleasure lovers and tourists, such clear, sunny weather was ideal; but for agriculture, ruinous. This remarkable weather continued until November, when without much warning it changed and became cold and windy.

On the other hand, there is such a thing as having too much rain with resulting floods. These are discussed in detail in a later chapter; but we may mention here the Johnstown and Dayton floods, and a few less disastrous storms when unusually heavy snowfall or ice storms have interfered with traffic, destroyed trees, and worked havoc with telegraph, telephone and electric light services.

The great blizzard of March 12–14, 1888, stands out prominently in the list of disastrous storms because heavy snowfall and high winds isolated the metropolis from the rest of the country. Again, heavy snow along the Maryland-Virginia Coast on January 27, 1922, resulted in the death of 97 persons at Washington when the roof of the Knickerbocker Theater collapsed. On November 30, 1921, an ice storm in Eastern Massachusetts did approximately $5,000,000 damage. On December 17–18, 1924, a severe glaze storm in West and Central Illinois caused a damage of practically

$5,000,000 to the wire services, exclusive of damage to shade and orchard trees. In fact that storm is classed as one of the most disastrous of its kind in the State of Illinois.

And so through a long list culminating in the hurricane of September 8, 1900, at Galveston, Texas, with its toll of 6,000 lives and damage of $30,000,000, approximating in total loss the destructive effects of a severe earthquake.

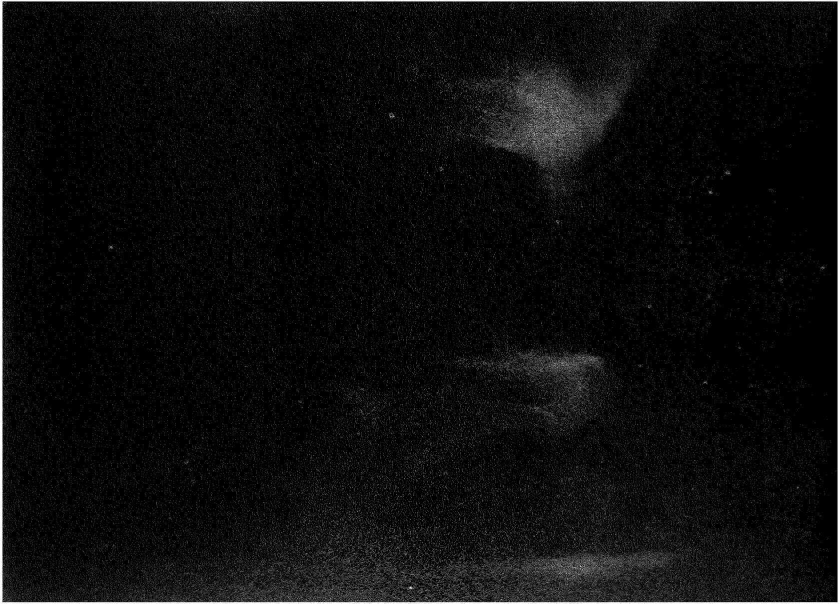
And what can man do to protect himself from such visitations? Can he apply brakes and slow down the winds; or cause the clouds to hold their load of water in suspense, carrying the rainfall elsewhere where it can do less damage? Not yet — chiefly because we know so little about the physical processes involved in the making of rain and in the starting of turbulence in the atmosphere. Air motion is initiated by differences in air pressure. Textbooks too frequently speak of difference in density as the first cause; but it is more accurate to regard pressure as the prime mover. Aerographers do not agree among themselves regarding the origin of the large whirls and counterwhirls of air known as cyclones and anticyclones. The word cyclone was introduced into our language by Piddington in the

first edition of his "Sailor's Hornbook," published in Calcutta in 1848. The word is from the Greek, signifying the coils of a snake, and he adopted it because his studies of the storms of the Bay of Bengal and of the Indian Ocean had led him to recognize that there was a circular motion to the wind. As early as 1698, Langford described in the "Philosophical Transactions" a West Indian hurricane and laid stress upon the rotary motion, comparing the storm to an enlarged whirlwind. Benjamin Franklin wrote to Jared Eliot in 1747 that he held the opinion, or as he expressed it,

> the very singular opinion that the course of the wind is from the northeast to southwest yet the course of the storm is from southwest to northeast.

A later letter of Franklin's, dated Philadelphia, 13 Feb. 1750, is so important in connection with the movement of the air and the passages of storms that it deserves quoting:

> You desire to know my thoughts about the northwest storms beginning to leeward. Some years since there was an eclipse on the moon at nine o'clock in the evening, which I intended to observe, but before night a storm blew up at northeast and continued violent all night and all next day; the sky thick clouded, dark and rainy so that neither moon nor stars could be seen. The storm did a great deal of damage all along the coast, for



WHIRLING ALTO-STRATUS

we had accounts of it in the newspapers from Boston, Newport, New York, Maryland and Virginia; but what surprised me was to find in the Boston papers an account of an observation of that eclipse made there; for I thought that as the storm was from the northeast it must have begun sooner at Boston than with us, and consequently prevented such observation. I wrote to my brother about it and he informed me that the eclipse was over there an hour before the storm began.

Capper, Horsburgh, Farrar, Redfield, Brandes, Dove, Reid, Thom, Piddington, Espy, and others established the fact that there was a rotary motion which in the northern hemisphere was counter-clockwise, while in the southern hemisphere it was clockwise. The invention of horn-cards or transparent protractors for anticipating the shift of the wind with the advance of the storm center made it possible for sailing masters to steer a course which would lead them away from the storm rather than into it.

Thus the early conception of a storm was that of a rotating mass of air, the air flowing around a central core. For many years there was much discussion as to the origin of the energy, one school maintaining that the heat set free by the condensation of water vapor was the source of motion and another school combatting this theory in favor of an origin

due to conflicting winds, cold, dry air from the northwest underrunning warm, moist air from the south and southeast. The most recent attempt at explanation of the origin of storms makes what is known as a Polar Front the cause of the travelling depressions which we call cyclones. It might perhaps be more logical to speak of the depressions as "sinks" and the large anticyclonic or high-pressure areas as "sources." The writer has also introduced the terms "infrabar" and "hyperbar" when these low- and high-pressure areas move slowly and stagnate. It seems demonstrable now that forecasts of weather, to be accurate, must take into account not only the pressure changes in individual storms but also the general pressure distribution.

The Polar Front suggested by Bjerknes is the front of a zone of cold air from polar regions in a wavy irregular form which advances and recedes, with tongues or surges of air, which in their progress from west to east cut off areas of warm, moist air from equatorial regions. There are faces of discontinuity; that is, a stream of warm, moist air flows by, without mingling with a cold, dry current moving in an opposite direction. Thus a torque or twist is established, and soon the rotary motion be-

gins. When pressures are plotted for different points on a map, the isobars will be nearly circular in a well-developed storm. It is seldom, however, that such conditions exist, and more often the isobars are elliptical or even V-shaped.

Moreover, there are difficulties, especially with slow-moving disturbances; and we have as yet no explanation that is entirely satisfactory. There are some who maintain that the sharp temperature contrast in the southwest portion of a cyclone is a result rather than the cause of motion. It must be remembered that a cyclone moves in a vastly larger stream of air and it is difficult therefore to represent the true motion of air in, through and out of such a "sink." At the ground the air flow as shown by a synoptic weather chart is spirally towards the center, not directly. Some of the air ascends in the center but most of it passes westward and through the low. At different heights in the free air, the direction of flow will vary.

But while the exact structure of a depression is as yet not clearly understood, and therefore the making of accurate forecasts is difficult, it does appear that it is now possible to forecast periods of excessive rainfall and on the other

hand droughts. A slow-moving depression, or, as it is called, a "stalled low" over New England, will be fed on the south side by warm, moist air. When an area of high pressure stagnates over Labrador, the storm will then move southeastward slowly and be accompanied by forty or more hours of rain. If such conditions occur when there is much snow on the ground, or when there has been insufficient run-off from previous rain or snow, then floods will occur in the various rivers.

On the other hand, it is not difficult to forecast scanty rainfall and the absence of floods. As mentioned above, the month of March, 1915, ushered in a period of scanty rain which continued until midsummer. There was less than 40 per cent of a normal precipitation for the four months.

Or take another illustration, this time on the far side of the Atlantic, where the rain-bearing winds come from the west and not as with us from the east — the drought of 1921, in Northwestern Europe, which resulted in less than half a normal rainfall. The usual low-pressure areas from the northwest (Iceland) were forced northward by anticyclonic conditions. The result was that Norway had an excessive rainfall and Southern England a deficit — in fact, a water famine.

Sir Napier Shaw in his book "Forecasting the Weather" gives on page 182 the chart for September 28, 1921, on which a forecast for fourteen days was issued. He adds, however, that

> a misadventure about the position of the British Isles with respect to the warm and cold divisions of the southerly current brought down some wild lamentations of the daily press on January 26, 1922.

In the United States, forecasts of weather are eagerly sought by railroads, transportation companies, and public utilities, in order that preparation may be made for rain, snow, ice, abnormal heat or freezing weather likely to prove injurious to perishable products in transit. Special forecasts in California are issued when frost is imminent, for a crop worth approximately one hundred million dollars may be ruined in a night. There is danger during December and January whenever a low passes eastward and southeastward over Central California, and is followed by an intense anticyclone from the north. The strong cold winds rob the fruit of its moisture. Then follows a night of quiet clear skies and intense radiation. Temperatures fall to 20° F., even in favorable localities, and a few hours of such low temperature means frozen oranges. The real injury to

the fruit, however, occurs in the defrosting rather than in the actual frosting.

Frost fighting in California is of special interest to us, aside from the general problem of the effect of weather on crops, in that we have here a clean-cut, definite attempt to meet the sharp fall in temperature and the destructive factor, whatever it may be, by the creation of artificial heat.

In 1895, the author and his colleague, Professor W. H. Hammon, began a campaign to give warning systematically of injurious frosts in the orange groves of California. It was a practical problem in which not only the giving of warnings was involved, but the design and application of methods of protection. It was questioned at the time in the press of Southern California, whether it would not be better to "sing sma'" on the frost problem. Why publish to the world the fact that frosts ever did occur in the land of golden sunshine? It would unquestionably hurt the sale of real estate. With the help of the Riverside Horticultural Club, however, and the effective championship of Mr. J. W. Reed and other growers, attempts were made to produce artificial heat in the orchards. First came the use of coal baskets, the invention of Mr. Edward Copely of River-

FROST

side. There are about forty baskets to the acre, each containing ten pounds of coal. This was followed by machines for producing smoke and wet smudges, and these in turn by oil-burners. Warm water was used on the Meacham Ranch, and a lattice-work cover on the Everest Ranch. The physics of the action of water was studied and before long the press of Southern California began to admit that frosts did occur, and to glory in the fact that with proper protective methods, the orange crop could be carried safely through weather colder even than known records indicated.

It was not long before the use of crude oil in the orchards came into general use; then followed organization of fruit growers into protective units; and now the orange growers feel when a cold wave comes, that the danger can be successfully averted.

I take this occasion to say that the Weather Bureau officials in California have saved more in the last fifteen years than the sum total of the appropriations for the whole service in forty years.

We have not time to go into the problem of health and weather. It is well known that there are days when nearly every one is depressed; and other days when even the most

dejected seem to experience the joy of living. These feelings are connected with the quantity of water vapor in the air and other factors. The laws of Massachusetts and other States pay attention to conditions of humidity and ventilation in mills and factories. The health of operatives is at stake; and very wise provision has been made for certain reports and inspections. Unfortunately, however, changes have not been made for some years and new knowledge regarding humidity has not been utilized. Some changes might well be made, which would prove helpful.

One other point may be mentioned: the need of accurate climatic data for the physician who has to send a patient to a given locality, which he now determines from certain tables of relative humidity or comparative dampness. These tables are not altogether reliable. It is the absolute humidity rather than the relative humidity which actively affects body evaporative cooling — the great factor in determining health.

Let us mention now some of the less serious experiences of a forecaster.

For eighteen years the writer was official forecaster for the Pacific Coast. Many and varied were the problems brought to his at-

tention, some of serious moment, others of only passing importance.

Brides-to-be naturally desired to know the probability of rain on the day set for the wedding. Sometimes grooms were on the anxious seat.

One impetuous lover asked for an official pronouncement that "in October the seas between California and the Hawaiian Islands are less stormy than in November or December." It developed later that the young people were anxious to be married early in October; and their parents said, "Oh, wait a month or so." An official forecast was used to convince the parents. The young couple were married in October and made a honeymoon trip that same month across the Pacific.

In a certain recreation ground known as the Chutes, there was a side exhibit of babies in an incubator. Now the babies did not thrive but sickened and seemed likely to die. The doctors were puzzled and as a last resort the forecaster was asked to help. He found the ventilating system working badly, the vitiated air of the exhibition room flowing into the smaller compartment containing the incubator. The air drainage was reversed and fresh air from the Pacific given to the babies first.

Whether this was the true remedy we know not; but the babies improved in health as soon as the change was made.

A certain cold-storage plant had much trouble with eggs. The plant engineers were sure that temperature was maintained nearly constant. The aerographer decided it to be a case of inconstant humidity rather than temperature. The degree of dampness varied and the lime in the egg shell was affected. A remedy was found by maintaining a constant absolute humidity.

A wholesale dealer in kid gloves lost a large stock by discoloration and spottedness. It was a case of too much water vapor. The building was in a fog-swept section and the windows faced on-coming fog-laden winds. Artificial driers were installed with success.

Some school children were poisoned by drinking adulterated milk. The milk dealer was arrested. The trial, which was written up large in the press, opened with the forecaster as first witness to prove a motive. There had been two warm days and therefore a preservative, in this case formaldehyde, was necessary. Weather records substantiated the District Attorney's contention and the milk dealer was heavily fined.

A police officer was murdered at a certain hour by a gang of thugs. One turned State's evidence. In his testimony he described the location and what he saw because of bright moonlight. The defence sought to discredit the testimony. The records of moonlight sustained it.

Suey Dip, an alleged Chinese highbinder, was caught by the police after the killing of another Chinaman. Police testified they saw him running in an alley after the shooting. He had no defence or alibi, but his counsel produced the weather records to prove that it was raining at the hour and very dark. The defence claimed mistaken identity. The jury evidently believed the weather records, for Suey Dip was acquitted.

In all the insurance cases arising from the San Francisco earthquake and fire the forecaster was the first witness called, not that he could foretell earth movements, but to prove the fact that there had been an earthquake and, of more importance in these suits, to establish the velocity and direction of the wind as determining the progress of the flames.

Much more could be told. There were damage suits ranging from carloads of cranberries spoiled by delay in transit, to losses of

life and limb by travellers; accidents due to falling signs and fences during high winds; injuries received by elderly near-sighted ladies falling into ditches which careless street workers had left open; complicated admiralty cases arising from collisions and storm accidents; and last but not least suits for money due to increase in weight of sugar and grain shipped from California ports dry and warm to European ports cool and damp. Such cargoes increase in weight by the absorption of water from the atmosphere. To whom does such money belong? shipper or shipowner?

But we need not go to the Pacific Coast for illustration of the effect of weather on industries and recreation. We have annually football games of some importance. In 1924, although the weather had been for many days dry and clear at New Haven, on the given date the rains descended. Those present said that the drainage of the Yale Bowl was unquestionably perfect, inasmuch as nearly all the water in the vicinity of New Haven drained into the Bowl. Or so it seemed. A memory even more painful is the experience of the preceding year at the Stadium in Cambridge.

Chapter III

THE STRUCTURE OF THE ATMOSPHERE

OUR atmosphere may be likened to a six-story building. That is, there are six concentric aerospheres or air floors. In this edifice the ground floor will be the *troposphere*, or airsphere, where there is much bustle and confusion — or, as aerographers say, much convection and turbulence. It is well named (the name was given by M. Lèon Teisserenc de Bort, a fellow worker with Professor Rotch) as the air shell in which there is much turning. The ceiling of this ground floor is approximately ten kilometers (six miles) above the ground. There is a mezzanine floor about half a kilometer above the ground; but for the present we will pay no attention to it, although just as in big buildings, these in-between floors contain very often the accounting departments, and, in a way, our accounts of weather are checked up in this half-way floor.

What is remarkable about this first floor (the troposphere) is that the temperature falls

at a fairly constant rate with altitude. This airsphere, however, is not of equal depth around the world but bulges out over the equator, and is crowded down at the poles.

The second floor is called the *stratosphere*, also the isothermal region, the former being the better name. The temperature gradients are no longer vertical but more nearly horizontal; that is, there is no constant fall in temperature as one rises. Explanation of why this is so will come later.

The third floor, or the one next above the atmosphere, is perhaps 60 kilometers above the ground. This is the region of meteors; and according to the recent determination of Lindermann and Dobson, the temperature at this height is considerably warmer than even in the mezzanine offices miles farther down. The fact of the matter is that we do not know much about this region and the meteoric evidence needs considerable corroboration.

The fourth floor we call the Kennelly-Heaviside layer; because while Heaviside announced its probable existence in Vol. XXXIII of the Britannica, December 19, 1902, Professor Kennelly had also announced its probable existence and published his view in the "Electrical World and Engineer," March 15, 1902.

At an elevation of about 800 kilometers (50 miles) a rarefaction exists, which at ordinary temperatures accompanies a conductivity to low-frequency alternating currents about 20 times as great as ocean water. We have here then an electrically conducting surface, which can reflect nicely certain electric waves such as radio waves. Thus waves transmitted to long distances may find an upper reflecting surface. When long-distance wireless waves are accurately measured, we shall know more about this region. This is also the region of the twilight arch. Sunlight illumines the upper air after the sun has gone below the horizon. The angle of the twilight arch varies from 15.5° to 18°. If the earth's radius is 6,367 kilometers, the radius multiplied by unity minus the secant of half the angle gives for the upper limit of the refracting medium 79 kilometers. A better value is about 60 kilometers (36 miles).

The fifth floor is the region of auroral displays, 100 kilometers and up to 350. The upper edges of auroral arcs have been measured by Störmer as high as 150 kilometers, but the rays go still higher, often to 300 kilometers. Indeed, Störmer claims to have measured one at Christiania which rose to 750 kilometers.

Vegard explains the aurora as due to a bombardment of solid nitrogen in molecular form by cathode rays; and states that he has identified the characteristic auroral line $\lambda = 5577$ Å[1] as due to this; but the explanation must be accepted with reserve.

The sixth floor, which we may call the Empyrean, or top story, we place at 500 to 1000 kilometers. All above this, we must call space and give over to the astronomers.

So it appears that our six-story air shell is not a very tall edifice. If we represent the distance from the earth's center to the surface by 1000 bricks laid end to end, then the thickness of the sensible atmosphere or height of the first story of our aërial edifice would be represented by a single brick; and the highest level yet reached by any human by 11 bricks; and the highest actual record that man has obtained (by sounding balloon) would be represented by 37 bricks.

One novel method of studying the structure of the atmosphere has been suggested recently by Dr. Willard J. Fisher, working jointly at

[1] An Ångstrom is the unit of wave-length of vibrations which produce lines in the spectrum. It is one ten-millionth of a meter; or as generally written 10^{-10} meter. Symbol A or Å.

Harvard Astronomical Observatory and at Blue Hill. Dr. Fisher remarks in one of his papers that if the sun were a point source, and instead of the moon we had a big silver screen out in space, every weather bureau would watch the earth's shadows with the keenest interest. Even as things are, here is promise of opening up a new line of attack — on the extent and character of the earth's atmosphere. Call it astronomy or aerography, whichever you please; it seems possible by close study of atmospheric conditions along the sunrise and sunset line, the illumination of the lunar face, the sharpness of the umbra edge and other details, to open up a new method of investigating atmospheric transparency.

To return now to the aërial edifice, let us examine in more detail the characteristics of each floor. We may omit chemical properties and note only air density, pressure, temperature and weight of water vapor per unit of volume. We have no special sense organism for recognizing variation in these physical properties. Although we live in the air and breathe it, we cannot see it, touch it, weigh it, taste it, smell it or hear it. We must use artificial eyes, ears and nose.

The thermometer is perhaps the readiest

instrument to use and we shall therefore give prominence to temperature conditions. Later, the variation of pressure and density will be discussed.

Suppose we had the power to walk on air, to tread it so rapidly that we could rise. Theoretically air is a rock; that is, it acts like a rock if you hit it hard enough and fast enough. Indeed it is this property, *the inertia of air*, which enables the airplane to go forward and upward.

If we start from the ground when the temperature is freezing, and rise a mile, or about one-sixth of the distance between the ground and the ceiling of the first floor of the atmosphere, we find that a thermometer with the Fahrenheit scale indicates a temperature of 16°. Going up another mile the temperature is zero; and at the end of a third mile, – 16° F. This is cold and the ascending aviator needs fur coat and heavy underclothes. At the end of the fourth mile it is – 32° F.; and a little higher the mercury in the thermometer will freeze. When he reaches the ceiling, six miles up, the temperature will be – 66° F., or if you prefer the Centigrade scale – 55° C. This is the rate at which the cooling occurs provided the air has a normal amount of water vapor.

CUMULUS AND ALTO-STRATUS

If the air was very dry the temperature would fall more rapidly and instead of − 66° F. the last reading would be − 142° F.

The pressure in the meantime has fallen to about half what it was on starting; that is, if we read the barometer at 29.96 in. starting, it will now read about 13.78 in. and the density, originally 1250 grams per cubic meter, would be only 650. A given volume of air at the top of the ground floor weighs only half as much as it did at the bottom, and exerts only half the pressure.

You will perhaps have noticed in using the Fahrenheit scale, that there are many minus signs, that is, readings below zero. Now zero on the Fahrenheit scale does not really mean zero, but only that it is 32 degrees below the freezing point of pure water. The freezing point 32° F. is not the freezing point of sea water nor of water in the cells of plants.

Thermometers were first used in Florence about 1620, and the earliest thermometers were quite unlike those of to-day. Without going into the history of thermometer development, let us regard the Fahrenheit scale as one that has served its day and generation, and one which no longer meets requirements. In its place men of science use another scale

known as the Absolute. Here the zero is a sure enough starting point, — the absence of heat, — quite unlike the Fahrenheit zero, which is really 459 degrees too high on its own scale. On the Absolute scale, the freezing point is 273.13° C. This, however, is also awkward, although it does away with minus signs; and therefore we have devised at Blue Hill, and used successfully for some years, a thermometer with a scientific scale. On this scale, zero is zero, the absolute zero, and 1000 represents the freezing temperature of pure water under standard conditions. There are no minus signs, the scale divisions are more detailed and the readings (we do not call them degrees, as that word is reserved for angular measures, where it properly belongs) more easily remembered.

With such a thermometer then we start again. The first reading is 1000, and we find that for every 50 meters (164 feet) we rise, the temperature falls one unit. At the ceiling the thermometer reads 800, so we know at once that the fall in temperature is $\frac{200}{1000}$ or $\frac{1}{5}$ of the whole fall between freezing water and absolutely no heat. This rate of cooling is for damp air; if we were in air without water vapor, the reading would be $\frac{365}{1000}$, which is more than a third of the whole fall possible.

This new thermometer has also been arranged for the benefit of those of us who have grown gray in harness and can not readily break away from old habits and units, for it shows all four scales, also the pressure of water vapor in kilobars and the saturation weight in grams per cubic meter of space.

Let us now return to the ceiling of the first story, which we have seen is about 10 kilometers high in the vicinity of Boston. The height of this ceiling is not uniform and constant. If we go south to the Equator, the ceiling is 17 kilometers (four miles higher than at Boston) whereas if we go to the North Pole, we would find it much lower, 6 kilometers (2 miles lower than at Boston); and there is some ground for believing that if we were at the South Pole and could make measurements for a year, we would find the mean height to be about 4 kilometers; that is, the first story of our aërial sky scraper is extensible and compressible, bulging out in the tropics and contracting noticeably in the arctic regions. This is not altogether a matter of expansion and contraction of air, although a column of air, like a rod of iron, expands when heated and contracts when cooled; but it is mainly a question of balance between incoming and outgoing radiation.

Let us forget the simile of the six-story building for a moment and instead picture the atmosphere as a suit of clothing which our old planet puts on to keep itself warm, just as we poor mortals do. The garment is made of two materials: one, the air itself, that is, the gases, we will liken unto cotton, and the other, the water vapor, we will liken unto wool. Now at the equator there is more water vapor proportionately than there is at the poles, and more opacity to long-wave radiation, that is, to heat waves, waves in the ether. Heat waves are long waves, their wave lengths varying from 10,000 Å to 20,000,000 Å, the longest being almost as long as the shortest radio wave. X rays are about 1 Å in length and gamma rays still shorter. Hence much water vapor, or wool, holds back the re-radiated heat waves, especially those of $\lambda = 14{,}500$ Å. Therefore the dividing line between the region of convection and the airsphere next above in thermal equilibrium will be higher. In fact this explains the reason why there should be a stratosphere above a troposphere. Gold in 1908 gave an explanation based largely on this action of water vapor. Humphreys, about the same time, reasoned out a relation between what is known as the effective tem-

perature of the earth plus radiation and the outer layers. The formula is simple. The temperature at the top of the lower layers will equal the temperature at the bottom of the top layers multiplied by the fourth root of 2; that is, 1.18. Or reversing the process, the temperature would read 950 at about 2500 meters, which we call the effective temperature; and 84 per cent of this will be approximately 800, which is what we actually find. Thus from the laws of radiation, we deduce the height of the stratosphere. This too is the top of cloudland, for a mixture of air and vapor can be lifted only to a height indicated by the degree of lowered temperature due to expansion. In the stratosphere the air is dry. It explains, too, why clouds are higher in summer than in winter and why, the fall being greatest, the lowest temperature can be sought over the warmest and dampest regions, namely, the tropics. And we find that the coldest spot on earth—in the air over the earth—is over the equator, some 17 kilometers high.

Let us follow an actual sounding made near the equator. The station is Batavia in Java, latitude 6° S. On December 4th, 1913, at 4.39 in the morning, the sounding balloon was set free, elevation 8 meters above sea level, pres-

sure 1013 kilobars, temperature 1090 kilograds (76° F.). The balloon rose at the rate of 4 meters per second. In five minutes the balloon was a mile high, the pressure 840 kilobars, the temperature 1060, or there had been a fall of 30 kilograds. When the balloon was two miles high (3200 meters) (which elevation was reached in 12 minutes) the pressure fell to 700 kilobars and the temperature to 1000, that is, a fall of 60 kilograds. At five miles the pressure was 400 kilobars, the temperature 920, approximately 34 kilograds per mile. At ten miles (16,090 meters) the pressure was 120 kilobars, that is, one-eighth of what it was at sea level, and the temperature 696, or a loss of 393 heat units or kilograds in 10 miles.

In one hour and eight minutes the balloon reached 17,000 m., temperature 670, and we find a dividing line, *the stratosphere;* for going higher, the temperature no longer fell, but even rose.

At	18,000	meters	 680
"	19,000	"	 700
"	20,000	"	 727
"	25,000	"	 783
"	26,040	"	 791

This last was the highest point reached, 85,433 ft. (It may be remembered that Mt.

Everest is 28,800 feet; so that the balloon therefore was three times higher.) The balloon burst and the recording part fell, sustained by a parachute. Coming down, there was at first a cooling.

At	25,000 meters	783
"	20,000 "	747
"	19,000 "	726
"	18,000 "	695
"	17,000 "	672
"	16,500 "	666

At this level, which is again the base of the stratosphere or the top of the troposphere,—the cold boundary,—the lowest temperature, 670 (− 90.2° C.), was recorded. This we may call the lowest natural temperature. (The lowest surface temperature known, 751, occurred at Verhoyansk in Siberia; the lowest Antarctic reading is 780.) As the balloon came lower the temperature rose and for the most part the rate is similar to that of the ascent, the warming being approximately 35 kilograds for each mile. Thus at 5 miles altitude the temperature was 912, and at the base 1095.

This is only one of many ascents at this station and of thousands made throughout the world.

On one occasion in a flight at Avalon, California, July 30, 1913, a sounding balloon reached an elevation of 32,643 meters, or four times the height of Mt. Everest. The pressure was as low as 10 kilobars, that is, .01 of the surface pressure. The temperature at the top was 845 and fell to 800 at the stratosphere, at 18,263 meters.

The greatest height reached by a sounding balloon was at Pavia, Italy, 37,000 meters, and the greatest height by pilot balloon 39,000 meters at Godhavn, or possibly 39,320 meters at Murmansk, March 29, 1919. The record for airplane altitude held by Sadi Lacointe of France, 11,145 meters, closely pressed by Macready of our own air service, 10,662 meters, was broken October 10, 1924, when Calizzo at Villacoublay reached 12,066 meters (39,716 feet). The greatest height reached by men in balloons is 10,300 meters; and the extreme height by kites is 9740 meters. Incidentally the first pilot balloon ascension in the United States was made at Blue Hill on July 7, 1909.

We now leave the stratosphere, which may extend to 75 kilometers, and pass into the region of the twilight arch and probably the Kennelly-Heaviside layer. Above this level we come to the seat of auroral displays, now

thought to be due to electric radiation from outer space, penetrating our atmosphere at a height of 100 to 105 kilometers. Most auroral forms have their maximum light intensity 10 to 20 kilometers from the lower edge. Auroral upper edges have been followed up to 130 to 150 kilometers, but rays are seen higher. Near the auroral zone, no rays are observed higher than 300 to 350 kilometers. At Christiania Störmer has measured isolated rays up to 750 kilometers. We shall say more about aurorae later. All above this level may — for want of a better name — be called the Empyrean. And this and space beyond, we leave to the astronomers.

Americans may well be proud of what has been contributed by their countrymen in connection with the exploration of the atmosphere. There was to begin with, the illustrious Franklin, a man of many interests. In his early forties he was interested in the movements of storms and about the same time proposed the use of kites as a means of studying the electrification of clouds. But the man who may most accurately be called the pioneer of air explorations was Dr. John Jeffries, who on November 30, 1784, made the first air sounding. He carried aloft a barometer, thermome-

ter, hydroscope, electrometer, compass and six stoppered bottles filled with water, which, after being emptied high in the air, were then tightly corked and sealed. The samples of air thus brought down were given to Cavendish for analysis, and the observations of temperature, pressure and other features reported to the Royal Society. Jeffries and his aeronaut Blanchard were in the air 1 hour and 25 minutes. They rose to a height of 2810 meters (9218 feet). The temperature fell from 1038 to 993 (from 51° F. to 28.5° F.), which compares favorably with the rate given by modern records. The pressure fell from 1016 kilobars to 721 kbs. (from 30.0 inches to 21.25 in.). In brief, the air cooled 1 heat unit (a kilograd) for each 62 meters elevation and the pressure decreased 1 unit of compression (a kilobar) for each 97 meters' ascent.

Near the ground the air was dry; but in the free air the relative humidity was higher. No indication of change in the electrification of the air was recorded, which is not to be wondered at, as the electrometer used seems to have been unsuitable.

Jeffries made another ascent which is even more remarkable. With Blanchard, he left Dover on January 7, 1785, at one o'clock in

the afternoon. This time they carried only a barometer and a compass. In one hour they had lost sight of the Castle at Dover. The balloon did not rise very high, for the wind was light and from the northwest. As the balloon failed to rise more than 200 meters, it was necessary to throw out all the ballast. Still settling, they threw out pamphlets, apples, biscuits, then the oars and the wings. Still failing to rise, they cut away the moulinet, then cast out the one and only bottle (full of *l'eau de vie*) and finally their overcoats, jackets and trousers. They were three quarters of the distance across the Channel and had put on cork life preservers and climbed into the slings, expecting to be immersed, when suddenly the balloon began to rise. They were five miles from the French Coast when an up-draught caught them and carried them rapidly toward and over the French cliffs near Cape Blanez (Blanc Nez). At 4 o'clock they landed in the Forest of Guines. They were not only the first air navigators to pass from one country to another separated by ocean waters, but they were also the first gliders, for there seems to be little doubt that the balloon glided up and over the cliffs as it came within the influence of the air current due to the up-sloping of the surface wind flowing from the north and

meeting a barrier in the high hills along the coast.

The barometer used by Jeffries, and also the thermometer carried on the earlier trip, are still in good condition and are in the possession of a great-granddaughter of Jeffries in Boston.

A word of praise must be given also to a third American, Professor Lawrence Rotch, who devoted his life to study of the structure of the atmosphere. No investigator of this generation has done more than Rotch for the acquisition of knowledge of the free air. He visited the various observatories of the world and studied their equipment and methods, returning to his native land to found an observatory where these methods might be applied and tested. The work done with kites, balloons and cloud-measuring devices, at Blue Hill Observatory, are lasting testimonials to his foresight and ability.

And no discussion of this nature would be complete without a reference to the treatise of Langley on the "Internal Work of the Wind," 1893, and the "Memoir on Mechanical Flight," 1887–1896; and above all the practical demonstration by Wilbur and Orville Wright that airplanes could be made and flown, carrying men through the air — thus realizing the dreams and hopes of preceding generations.

Chapter IV

CLOUDS, FOGS AND WATER VAPOR

Lo! the poor Indian, whose untutored mind
Sees God in clouds and hears him in the wind.

ALEXANDER POPE, poet and philosopher, pictures thus the savage deifying the clouds. We who know that clouds are but masses of water vapor made visible by cooling — however that cooling may be brought about — do not look at clouds with the awe and reverence of the untutored savage. Perhaps we have lost something! For we regard clouds rather casually, unless indeed we happen to be caught unprepared in a downpour. Then we scan the skies, watching the clouds more or less intently, trying to forecast the cessation of the rain. And when the rain ends we go our ways and forget.

Robert Louis Stevenson once wrote that if mankind were to be charged sixpence for each beautiful sunset, doubtless these would be more appreciated; and this we may paraphrase by saying, that if we had to pay a stiff admission fee to some great stadium where ships and

fleets made of water, the wonderful clouds, sailed overhead through the air, the stadium might be thronged with admiring crowds.

The wonderful thing about clouds is that you do not have to pay to see them; one does not even have to travel abroad to see them. Nearly every form can be seen by one who watches, even from a city bedroom window.

Man is himself a cloud-maker. He is a machine at work exhaling a mixture of air, largely carbon dioxide and water vapor. The last is generally invisible but can be seen clearly when the temperature is low enough. It is then that our breath is exhaled as a visible vapor or cloud. Our lungs, like the exhaust of steam plants, throw off surplus water, which has been vaporized. And just as we do not always see our breath, so we do not see all the vapor masses in the free air. In other words, there are the unseen clouds — masses of water vapor drifting overhead in various shapes, long streaks, short rounded heaps, shallow banks and deep streams — ready to flash into sight the moment they become chilled enough; that is, when the cloud point, heretofore called dew point or point of condensation, is reached. We can detect the presence of these unseen clouds by an electrometer. We can follow them by

SUNSET ABOVE THE FOG

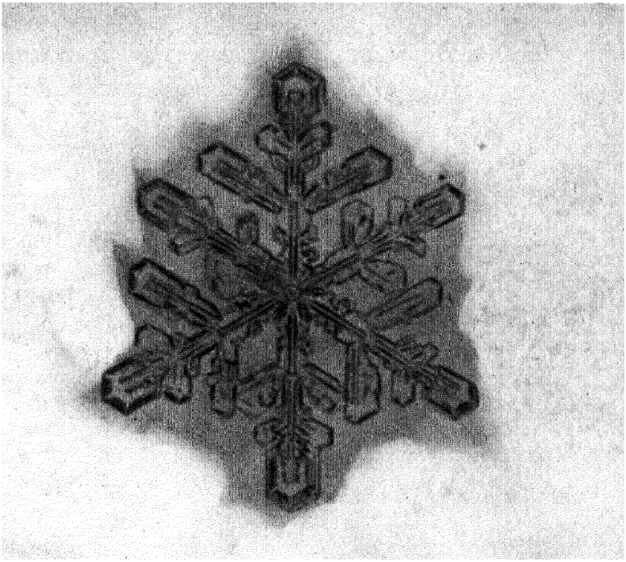
recording their electrical action, for these clouds, like their visible brethren, carry an electrical charge. Here is a fascinating line of experimentation, this study of cloudland, not alone by what the human eye sees, but also by the artificial eye, the charged needle between the charged quadrants of an electrometer, faithfully telling us how highly electrified these vapor masses are. With an insulator highly charged, we can actually tear away from these vapor masses minute particles of what we may call cloudstuff. In the chapter on lightning we will show how to capture minute drops from a jet of electrified water.

Let us now see what a drop of rain really is. Air is a mechanical mixture of certain gases, the predominant one being nitrogen (atomic number 7, atomic weight 14.01). There is no chemical combination with the oxygen (atomic number 8, atomic weight 16) or any of the other gases. So far as is known there is no hydrogen (atomic number 1, atomic weight 1.008) in the atmosphere; which is fortunate for us, else we never could strike a match without blowing ourselves and our neighbors into fragments. On the other hand, water is a chemical combination of two gases, the ubiquitous oxygen and the fugitive hydrogen. Two mole-

cules of hydrogen with one of oxygen make a molecule of hydrone, which in turn makes water, the proper notation being $(H_2O)_2$ or H_4O_2. When water vapor condenses at a temperature of 1000 or below and crystallizes, we have the familiar ice crystals and snowflakes. Water may, however, be sub-cooled without assuming the solid state. Let us for a moment digress, carrying the cooling of the water vapor into the solid state, and see what a snow crystal is like.

X-ray photographs of ice by Hull, Dennison and others, show that ice has a lattice which is built up of two sets of right-triangular prisms interpenetrating one another. The molecules lie at the vertices of equilateral triangles, each molecule directly above molecules of the other planes, at intervals of 7.32 Ångstroms. The axial ratio is 1.62, in good agreement with the crystallographer's 1.617. The number of molecules in a cubic centimeter of ice as calculated by Dennison is 31,540,000,000,000,000,000,000, or, 31,540 million billions, if a billion is a million million. The number of H_2O molecules in each unit prism is 2.04.

Raindrops are formed under conditions of saturation whenever a sufficient cooling of



SNOW FLAKE

MAGNIFIED TWENTY DIAMETERS

water vapor occurs. Thus shower rain is generally the result of cooling a mass of vapor by elevation, which produces expansion, hence cooling and lower temperature. If only gravity acted, rain would fall; but there are other interfering factors.

There is about one cubic centimeter of water in 10,000,000 cubic centimeters of air or one drop of rain in 5 liters (a liter being a little less than a quart).

A cloud droplet	is	0.1	mm.	in	diameter, or less
A fine raindrop	"	0.25	"	"	"
A medium "	"	3.00	"	"	"
A large "	"	6.00	"	"	"

If the drops are electrified, and they often are, there is an attraction; that is, a positively electrified drop coalesces with a negatively electrified drop, and then you really do make a drop of rain.

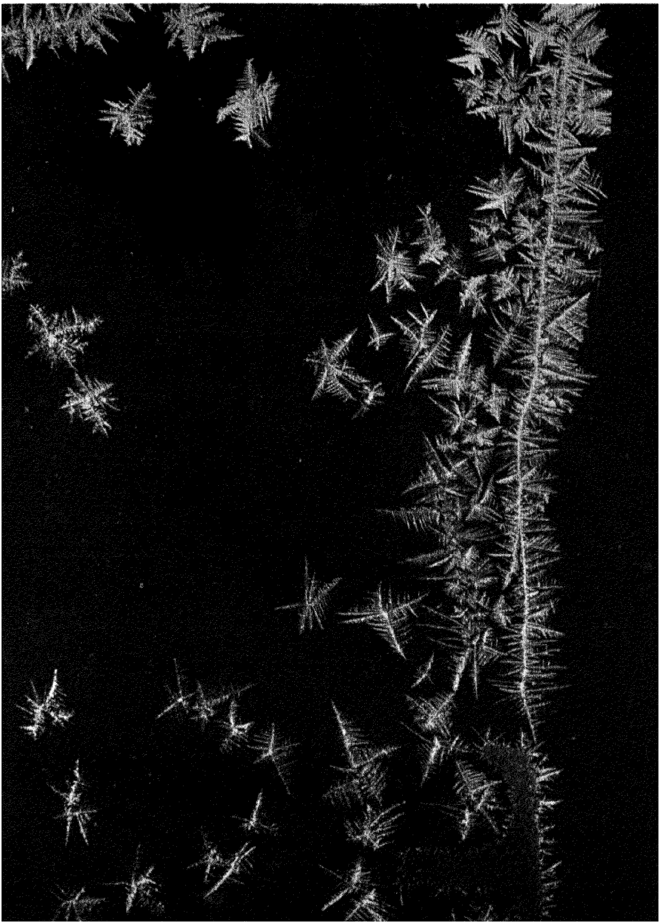
A whole chapter could be devoted to this single phase of forcing cloud particles to coalesce and make rain; and the reverse problem of breaking up the drops, changing the condensed visible vapor back into invisible vapor and thus scattering the cloud, dissipating fog and preventing rain.

During a heavy smoke fog in London one

may breathe in 24 hours 500,000 million of smoke particles. The Smoke Abatement Committee is responsible for the statement that if these particles were placed end to end, they would make a string 400 kilometers (250 miles) long. But it would be a very, very thin string, less than 1.5 microns in diameter. A micron is $\frac{1}{1000}$ of a millimeter, or a millionth of a meter. It is rather interesting to think of each and every person in the streets of London during a thick fog, breathing in that much solid smoke.

If we could collect the rainfall for a year over the entire surface of the globe, that is, over an area of 510,000,000 square kilometers, or 196,940,000 square miles, we would find an average depth of 74 centimeters or 29.13 inches. It would need a tank 377.5 kilometers (234.6 miles) long, deep and wide, to contain the water.

Our Atlantic Coast cities, as well as the Gulf cities and certain areas on the North Pacific Coast and in the mountains of North Carolina and Tennessee, receive double the average depth, while localities in the interior receive less than one half. New York, for example, has an average annual rainfall of 114 cms.; Philadelphia 103; Baltimore 110; Boston 111; Nor-



FROST CRYSTALS

FROST FERNS

folk 127; Charleston 136; Pensacola 144; New Orleans 146; while at Cheyenne the amount is only 13 cms.; at Santa Fe 20; at Winnemuca 22; at Tonopah 25; at Denver 35; and at Salt Lake City 40.

A balance sheet showing the ratio of evaporation to precipitation is given below. In most of the maps of rainfall of the globe, the depth over the oceans has been overestimated.

THE BALANCE OF PRECIPITATION AND EVAPORATION BY LAND AND SEA [1]

In 1920 Wüst[2] published the results of observations of evaporation at sea[3] revising Brückner's estimate of the average evaporation, and thereby modified Fritzsche's results. Wüst's paper does not contain the complete balance sheet, however, and it is left to the reader to refer to Fritzsche's thesis and reconstruct such a balance sheet himself. The matter is of such importance, however, that it is worth while to give the figures. In the following table the unit of area is 10^8 square kilometers

[1] See *Meteorological Magazine*, Vol. 59, No. 697, p. 6, February, 1924.

[2] Wüst, Dr. George, *Die Verdunstung auf dem Meere* (*Institut für Meereskunde*, Berlin, 1920). See also *Meteorological Magazine*, Vol. 57, February, 1922, p. 8, for discussion of this paper.

[3] Evaporation from small vessels carried on board ship was estimated by the change in the saltness of the water. In the reduction of the observations the strength of the wind over sea and of relative wind over the vessels was allowed for as well as temperature differences, etc.

(the square on an earth-quadrant), the unit of depth is a centimeter, and the unit of volume is 1000 cubic kilometers. The fundamental data are shown in boldface, all with the exception of the 82 cm. for evaporation over the sea, coming from Fritzsche's paper. The other figures are obtained by mere arithmetic. It is remarkable that the average rainfall for the whole globe is estimated as practically the same as the average for the sea alone. It is a little below the average for England, which is 80 centimeters.

Unit		Area 10^8km.^{2}	Annual Depth cm.	Annual Volume 10^3km.^{3}
Aperipheral Land	Rainfall (Fritzsche)	**0.32**	**33**	10.5
	Evaporation......	0.32	33	10.5
Peripheral Land	Rainfall (Fritzsche)	**1.17**	**87**	101.5
	Run-off = **30%** (do.)	1.17	26	30.5
	Evaporation = **70%**	1.17	61	71.0
The Sea........	Evaporation (Wüst)	**3.61**	**82**	296.0
	Run-in (from land)	3.61	8.5	30.5
	Rainfall..........	3.61	73.5	265.5
The Globe	Rainfall..........	5.10	74	377.5
	Evaporation......	5.10	74	377.5

The researches of Fritzsche and Wüst do not furnish direct information as to the distribution of rainfall over sea.

From the data given above it would seem that the total rainfall for the globe is much less than the evaporation.

The clouds then represent only visible vapor. Much invisible vapor remains overhead.

Cloud observation can furnish therefore only an incomplete record of the volume and movement of the vapor.

Clouds are not always accurate indicators of air flow, yet in the main are significant in determining wind directions and velocities at flying levels. How do we measure the speed and direction of the clouds without using an airplane? The instrument used (a Nephoscope) enables one to get the cloud height, direction and velocity, from a window without leaving the room; and what is particularly interesting is that the process of cloud-building is used to determine the cloud height. When this is known, also the distance travelled, the speed and direction follow. The instrument consists essentially of two parts, one a cryoscopic part for getting the chilling due to expansion, and from this the temperature of condensation, not the temperature of evaporation but a lower temperature. The second part, the nephoscopic, gives the height by triangulation.

Evaporating a film of water on the bulb of a thermometer lowers the temperature. For example, the readings are in this case, 1095 and 1065. The difference multiplied by a cer-

tain factor (nearly .2) is 6. Now the vapor at the temperature of evaporation exerts a pressure of 20 kbs., not a very great pressure to be sure, when we remember that atmospheric pressure is 1000 kbs. Twenty kbs. minus 6 kbs. is the pressure at a lower temperature known as saturation. This is 1044. In other words, starting at 1095 (78° F.) we must lift the vapor until it cools down to 1044 (54° F.). For each 1000 meters elevation the cooling approximates 30 heat units. Hence to cool the whole 51 units we must go 1700 meters high before a cloud will form. By either actually going up in a plane, or sending up instruments, we find this to be a true elevation for the cloud base; but not always, for often there is an inversion of temperature and this complicates the problem.

A new term which is coming into use among aerographers is potential temperature. A cloud or mass of air plus vapor can stay far above the ground only when conditions are in stable equilibrium. That is, the temperature and pressure of the cloud mass must be such that if forced down to the ground it would have the same pressure as the original surface air, and a much higher temperature due to compression, providing there was no means of

ALTO CUMULI

carrying away the increasing heat. The temperature which the air and vapor would have at the ground is the potential temperature and is plainly always much above the initial surface temperature.

Shaw and Fahmy have made it possible by plotting temperature on an ordinary scale and potential temperature on a logarithmic scale, to construct diagrams giving the entropy, for it happens that the entropy or degradation of heat energy is proportional to the potential temperature. Thus dealing with saturated air, the curves give quantities of heat as represented by enclosed areas; and we can compare theoretical values with actual values as obtained by soundings, thus getting the values of the transformation of heat into energy of motion. The conception of entropy is difficult and perhaps the phrase which will best convey this is the running-down of heat. Specially ruled plotting paper is needed for such problems.

But there is something more than convection going on in the air. Generally in addition to an up-current varying from 1 to 5 meters per second in quiet fair weather, and 15 to 30 meters per second during thunder-storms, there are down-currents, generally slower, but

of greater volume. There are also cross-currents or horizontal flows which result in stratification. Hence it sometimes happens that even when the clouds hang heavy, when the condensation has been carried far and drops of 2 or 3 mm. in diameter are forming which normally would fall with a velocity of 5 or 8 m/s., a strong horizontal current will check further cooling and cloud building. Although the clouds may threaten, no rain reaches the earth. A quotation from a recent paper of Sir Napier Shaw on "Resilience, Cross Currents and Convection," may make the argument clearer, using as he does the homely simile of a cup of tea containing curdled milk, well stirred.

> Anyone who will watch the surface of a cup of very hot tea containing curdling milk will realize that the vertical motion due to thermal causes may be and probably must be a complicated process.

In other words, it is to be remembered that cold air may be forced upward by dynamical action of eddy motion, independently of thermal conditions.

Certain types of cloud are undoubtedly due to a rolling motion caused by strong cross currents. We can find illustrations in certain types of the cumuli and the alto-cumuli.

There are also clouds due to the crossing of these cross-currents, one stream of air passing over another denser stream, hence billows.

Clouds were without systematic names until 1802, when Luke Howard, a chemist of Tottingham, London, proposed a system which was accepted and used without change for more than a hundred years. Lamarck, in 1801, described certain forms but he himself was not particularly successful as a meteorologist. It is said that Napoleon was often sarcastic at his expense. Howard was very fortunate. His work was acclaimed at home and on the Continent as worthy of great praise. Goethe wrote him many laudatory letters, which, read to-day, seem to be extravagantly phrased.

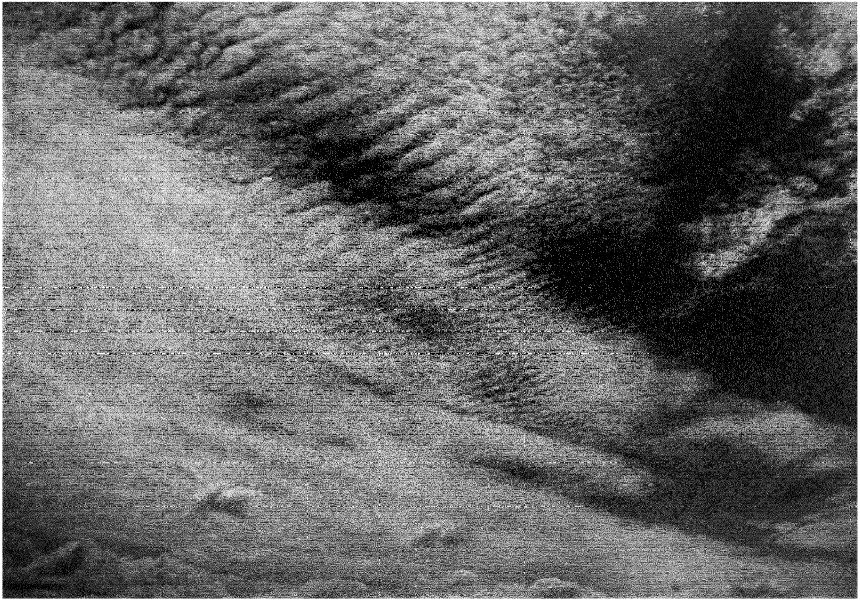
The weakness of Howard's classification is that it is based entirely upon appearance or form, not on origin, formation or significance. He made three prime divisions: the layer cloud, the lump cloud and the curl cloud. If now we use the Latin equivalents for these types, we have *stratus*, *cumulus* and *cirrus*. Add also the Latin word for fog or cloud, *nimbus*, which really means a cloud without form, but restrict the meaning to rain; and we have the essentials of the system.

From these four basic types, Howard made several combinations, such as strato-cumulus, cirro-cumulus, and cirro-stratus. The strato-cumulus type is perhaps the most frequently seen of all cloud forms.

The word *fracto* (not used by Howard) is now in general use to designate a cloud form in which the mass is broken into small divisions. Thus we have fracto-stratus, fracto-cumulus and fracto-nimbus.

In 1890 there was a conference of meteorologists from various countries and an attempt was made to establish an international cloud classification. Ten types were agreed upon, and arranged in three major and two minor levels. Beginning with the highest, the cirrus type, at an elevation of 9000 meters (5.6 miles or 29.500 feet), we drop down to an intermediate level 7000 to 3000 meters (23,000 to 10,000 feet), where we find cirro-cumuli, alto-cumuli and nimbus clouds. High fogs and stratus are formed generally below 1000 meters. Cumuli and cumulo-nimbus have bases 1500 meters or more; and their tops vary from 2500 to 9000 meters.

It is hardly necessary to give the details of the ten types of the International Cloud Classification. A more logical classification is that



ALTO CUMULI

of H. H. Clayton, based upon altitudes. Five levels are given, called stratus, average altitude 500 m.; cumulus, average altitude 1600 m.; alto-cumulus, 3800 m.; cirro-cumulus, 6600 m.; and cirrus, 8900 m.

Many long names have been given to various clouds; but these seem quite unnecessary. A cloud may have any shape or appearance and we can call it anything we like, and if we want to be impressive in the presence of those who do not know to the contrary we can use Latin words. Thus if one thinks a cloud looks like a Grizzly Bear, he can name it *Nubis cumulus ursus horribilis;* but in a moment or two the cloud mass that looked like a bear will have evaporated or changed — and after all, in Shakespeare's words, it was only "an airy nothing." There are people who will call a certain dark cloud cumulo-nimbus grandineus, but most of us prefer to say, hail cloud.

Finally, it is interesting to recall that the only reference to the New World which can be found in the plays of Shakespeare, is in connection with a cloud. In some way unknown to commentators, he had heard of the Bermudas (the Bermoothes) and in "The Tempest" puts into the mouth of the clown, watching a cumulo-nimbus cloud, these words,

Yond' same black cloud, yond' huge one looks like a foul bombard that would shed his liquor. . . . Yond' same cloud can not choose but fall by pailfuls.

The clown made a forecast; and lo! the forecast was verified.

Chapter V

LIGHTNING

A NATIVE of Boston, while perhaps not the first to suggest the identity of lightning with an electric discharge, was the first to set forth clearly the fact that certain clouds were electrically charged and that the discharge or lightning was to be regarded in all respects as the discharge of a large condenser.

As early as November, 1749, or three years after he first saw a Leyden jar, Franklin definitely announced his conclusion.[1] Again in 1750, he speaks of the "fire of electricity and that of lightning being the same," and estimates what a cloud ten thousand acres in extent would do if electrified and discharged. This is what led to the lightning rod. That part of his remarks on the subject is worth quoting:

I say if these things are so, may not the knowledge of this power of points be of use to mankind in preserv-

[1] See Letter V of his *Experiments*, 5th Edition, London, 1774.

ing houses, churches, ships, etc., from the stroke of lightning, by directing us to fix on the highest part of these edifices upright rods of iron, made sharp as a needle and gilt to prevent rusting. . . . Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike and thereby secure us from that most sudden and terrible mischief?

Thus it is plain that Franklin's first purpose was to utilize the discharging property of points. Nothing, however, seems to have been done that year, 1750. In the following year, in a letter to C.C. (Cadwallader Colder) of New York, Franklin makes a suggestion which is to some of us of greater moment than the earlier suggestion. It is in brief that the measurement of the power of a lightning flash was not beyond the scope of man's knowledge. In this letter he said:

The greatest known effects of common lightning may I think without much difficulty be exceeded in this way. [He refers to a proposed increase in the number of Leyden jars; and goes on to say that] a few years ago this could not have been believed and even now may seem to many a little extravagant to suppose. So we are got beyond the skill of Rabelais's devils of two years old who he humorously says had only learnt to thunder and lighten a little round the head of a cabbage.

Rare old Ben, with his foresight and quaint humor! One hundred and seventy-five years

have passed since he suggested that we "out-lightning lightning," but we have not yet succeeded in duplicating a flash of lightning. We have some near-lightning flashes and there have been many attempts to build up batteries of numerous cells and so get tremendously high potentials and amperages; but as yet we have not duplicated lightning, although the lightning generator of the lamented Steinmetz and the high-tension work of Peek come very near accomplishing it.

In the following year, 1752, Franklin experimented with lightning. Some time in September lightning rods with points were erected on the Academy and State House, but the first experiments of charging and discharging insulated metallic rods under electrostatic induction during the passage of a thunder-cloud, were made in France by Abbé Mazeas. There were also some tests made in England. Franklin did not, however, hear of these until the end of June. It is therefore very unlikely that he flew a kite in June as commonly stated; that is, June 1752. This report seems to rest upon Stuber's statement, which is, "early summer of 1752"; but it must be remembered that Franklin was an old man when he and Stuber discussed these matters, and the "Life of Frank-

lin" was not published until long after Franklin's death.

And now we come to the famous kite experiment. The date of the letter (XI) in the "Observations" from Franklin to Peter Collinson, F.R.S., London, is October 19, 1752. The date given in the "Philosophical Transactions," 1752, p. 565, is Philadelphia, October 1, 1752. The date in Franklin's own paper, "The Pennsylvania Gazette," is October 19. But the date or dates when the kite was actually flown, we know not. Tradition is that the kite was flown on a vacant lot in Chestnut Street.

The description of the experiment is detailed in some respects and far from satisfactory in others. We may say at the outset that the popular conception as embodied in illustrations on bank notes, letter heads of insurance companies, etc., is not at all true. This is the popular myth, and like Washington's hatchet, or Tell's arrow, catches the popular fancy; and will probably live on, despite all attempts to set forth the facts. Franklin did not stand out in the open toying with a key on a piece of silk at the end of a kite string, the kite flying close to dark, rolling thunderclouds. He particularly enjoins that the observer must be under shelter so that the silk

CUMULO STRATUS

may not be wet. He makes a curious slip in saying that "the kite with all the twine will be electrified and the loose filaments of the twine will stand out every way and be attracted by an approaching finger."

How can one on the ground tell if the kite is electrified? Moreover, those of us who have tried to duplicate the experiment know that the effects described are not those experienced during a thunder-storm, but are to some degree such as are experienced in fair weather and are due to differences in potential.

The experiment is a dangerous one. The condition is so dangerous that kites are always hauled down promptly on the approach of a thunder-cloud, or the hearing of distant thunder. The person at the end of a kite wire during a severe thunder-storm will be killed nine times out of ten.

Franklin was too wise and too cautious to expose his son to certain death, as given in Stuber's description:

> While waiting for the erection of a spire, it occurred to him that he might have more ready access to the region of the clouds by means of a common kite . . . he went out into the commons accompanied by his son to whom alone he communicated his intentions, well knowing the ridicule which too generally for the interest of science awaits unsuccessful experiments in philosophy.

He placed himself under a shade to avoid the rain, — his kite was raised, — a thunder cloud passed over it, — no sign of electricity appeared. He almost despaired of success when suddenly he observed the loose fibres of his string to move toward an erect position. He now presented his knuckle to the key and received a strong spark.

One may remark that going out on the common to fly a kite during a thunder-storm is not just in keeping with a desire to try out the experiment in quiet and unknown to the public, "fearing the ridicule, etc."

In brief, if Franklin had really flown his kite during a lively thunder-storm, there might have been a coroner's jury next day holding an inquest on the remains. Franklin understood better than any other man of his day, what we may call the killing power of lightning; and those of us who have had much to do with kites and thunder-storms subscribe to Voltaire's criticism, "There are some great lords whom it does not do to approach too closely, and lightning is one of these."

But altogether aside from the kite experiment, Franklin demonstrated the electrical character of lightning.

We pass over the controversy which raged on the merits of points and the efficiency of rods as conductors. We have lived to learn

that lightning is not an ordinary current discharge. It does not follow the law of least ohmic resistance. It is not like a battery current magnified a million fold, nor yet a magneto machine current. It is a sudden breakdown of air resistance, resembling an enormous condenser discharge. It is not necessarily an oscillating discharge like the condenser, but is probably unidirectional.

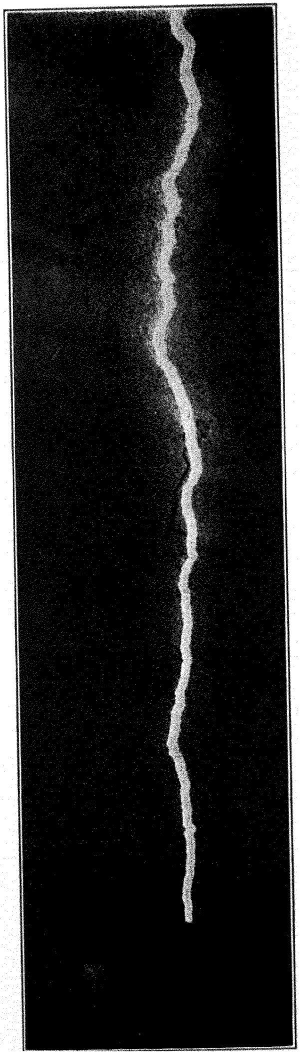
It has a very steep wave front and that perhaps explains one peculiarity of lightning, one that differentiates lightning from other electrical discharges; and explains why lightning effects are so different from other electrical discharge effects, except the artificial lightning made by the General Electric Company at their high-tension laboratory at Pittsfield, Massachusetts.

Lightning is, as Dr. F. W. Peek (to whom I am indebted for the picture which follows, showing *near lightning*) puts it, an electrical explosion. The power over short intervals may be millions of kilowatts. Peek has constructed an impulse generator, excited at 60 cycles A.C. two million volts. Lightning is of extremely short duration—a ten-thousandth of a second or less. Currents as high as 10,000 amperes have been obtained.

It is to be noted that most lightning discharges on transmission lines are not direct strokes but electrostatic induction phenomena. This is something Franklin did not know. A flash a mile away may result in a release of the induced charge on a line; and the effect is the same as suddenly sending a high-voltage wave over the wire. Peek states that in Colorado he has measured some induced lightning that had voltages as high as 500,000 volts.

In the direct stroke, or what we may call real lightning, the voltage may easily be one million volts per meter; and for a flash 500 meters long, 500 million volts. Peek, by approximately direct measurement, finds the voltage of a flash to be 100,000,000; and he observes that during a severe thunder-storm the voltage will vary over a wide range; also that there are many induced strokes at low voltages, a smaller number at moderate voltages, etc.

What is the power of a flash of lightning? It has been calculated by E. Poirson that a cloud with a bottom radius of 500 meters, and 400 meters above the ground, will have a capacity of 0.055 mfd. The earth capacity is assumed to be 700 mfd. A bolt from the cloud to earth, or from earth to cloud, may



McAdie

LIGHTNING

have a potential of 50 million volts. Assuming an air resistance of 10 megohms, the frequency would be nearly 25,000 cycles a second. Nearly 70 million joules (a joule being 100 million ergs) would be liberated, or nearly 70 million kilowatts in the thousandth of a second. At the usual price of 10 cents per kilowatt hour, the bill for the energy per flash of lightning would average $2.00. Probably no two thunderstorms are alike, and so no two bills for the energy expended in lightning flashes for any two storms would be the same. T. C. R. Wilson estimates that the electrical energy going to waste in an average thunder-storm may amount to 735,000 kilowatts, or 1,000,000 horse power.

What is the frequency of lightning flashes? In a severe thunder-storm which occurred in London July 9–10, 1923, there were recorded on a brontometer 6924 flashes in six hours. The average per minute was 19 and the maximum 47. At the rate quoted above, the bill for electrical power used up would be about $3000, unless the rates were cheaper than those given. And this reminds us of the distinction made by the small boy between electricity and lightning. He said, "You don't have to pay for lightning!" But he might have added if

he had stopped to think, that very often we do have to pay and pay heavily for the damage done by lightning. We shall give later some suggestions bearing upon the protection of life and property during thunderstorms.

There are records of flash rates of 50 per minute and we have counted as many as 30 visible flashes.[1] And there are also invisible discharges. Working with an electrometer in a dark room in the tower of the Smithsonian Institution at Washington, a record was kept by an observer stationed outside, of the number of flashes. Another observer inside timed flashes as indicated by the return of the potential to zero. All of the flashes seen outside coincided with times as recorded by the observer inside; but he also had many more flashes not recorded by the other observer.

There are all kinds of flashes — from the comparatively slow-moving horizontal to the intense direct vertical, from meandering flashes to impulsive rush discharges. And perhaps the greatest puzzle of all is the so-called ball lightning — a red luminous ball or hollow sphere from 10 to 20 centimeters in diameter, some-

[1] On Dec. 25, 1923, at Pretoria, during a severe thunderstorm 360 flashes were recorded in three minutes. For about one hour there were approximately one hundred flashes per minute.

times hazy in outline, sometimes dazzlingly bright, accompanied with a humming or hissing sound; and disappearing sometimes silently, sometimes with a light snap and sometimes with a blinding explosion. Generally there is a trail of smoke. As a rule, its existence is brief, a few seconds. Near the ground or in a closed room, a ball of lightning moves slowly — about two meters a second. Brand has made a list of 600 records of ball lightning, and these and other cases have been analyzed by Simpson.

How Shall We Lessen the Losses from Lightning?

In a battle, a hundred bullets are fired for each soldier killed. It is something like this with lightning flashes. There are a hundred discharges for every bolt of lightning that hits a person. Fortunately, too, of every hundred streaks of lightning, about ninety are from cloud to cloud, or spill-over discharges of moderate electrical energy, mostly horizontal and doing no damage whatever. About ten flashes in a hundred come vertically, that is, down to earth in a straight line. Some flashes come sidewise and seem to be crooked, although few, if any, flashes zig-zag like the teeth of a

saw, as artists generally depict lightning. We have many photographs where a flash bends on itself and changes direction three times; but such flashes are infrequent and as a rule not dangerous. The intense straight flashes are the ones to be feared; and he is not wise who stands out in the open when such flashes are seen.

Our first bit of advice: Do not stay exposed on a field when dark, heavy clouds are overhead or coming slowly from the west or south. Get under cover if possible.

Second: Do not stand under a tree with thick foliage, in order to keep dry. You are forming a part of the line of discharge, since the body, more particularly if the skin is moist, is a better conductor than the trunk of the tree. More people are killed by lightning in this way than probably any other. The lightning flash while long is not very wide and therefore, when several people are standing under a tree, one may be killed and others near him escape.

Third: Do not stand in the doorway of a barn or at a window in proximity to a chimney. There are currents of air or winds, and the lightning follows to some extent any draft or column of rising air, especially warm air. This is one reason why barns are so often struck.

Fourth: Do not laugh at your neighbor's nervousness during a severe thunder-storm. There is a good reason to be nervous. Fortunately, as said above, the great majority of flashes are harmless; and even if one is in a building that is struck, the damage in ninety-five cases out of a hundred is confined to ripping out plaster or knocking off slates, and tearing off projecting timbers. But there are times when the storm clouds descend to earth; and amid darkness, the flashes are heavy and numerous. At such times there is danger. Sometimes in mid-August, after a period of hot, sultry weather, such a storm breaks; and the clouds move slowly. At such times it is dangerous to be near a chimney, or a tree or a flagpole, or a metal clothesline.

Fifth: Do not tie stock to wire fences, and do not come in contact with such.

Sixth: There is no particular advantage in going to bed, standing on glass, or rubber, or any good insulator. However, these expedients have a psychological side and give one a feeling of security and more confidence. The probability of being struck in an ordinary residence is very slight.

Seventh: If you are near a person who has been struck, make every effort to resuscitate

him or her. Put your first-aid lessons into practice; for only rarely does lightning kill outright. Generally people are stunned; and all that is needed is a little artificial respiration to restore them to consciousness. Do not give up. Try for an hour and of course get a doctor as quickly as possible.

Eighth: If you are in a trolley car, and a flash comes in and burns the fuses with a roar and a blinding flash, sit still. The danger is over, and while you may be frightened and it is all very unpleasant, you are not likely to be hurt, unless you are close to the arc.

Ninth: The antennae of radio outfits should be grounded and all wires, as far as possible, kept outside. Aërials are sometimes struck but the damage is chiefly melted wire.

Tenth: If your house is provided with good lightning rods, well grounded, you need not worry. Moreover, dwelling houses in city blocks are practically safe. Travelling in automobiles is not dangerous; but do not stop under trees or remain standing on hilltops; for while it is quite true that rubber tires insulate fairly well when dry, this condition does not hold during prolonged rain, when everything is soaking wet; and if the machine is under a tree with wide-spreading foliage, you become part of a path favorable for discharge.

We hope it will not be considered irreverent if we call the ten rules the ten commandments of lightning. Incidentally it will be remembered that the ten commandments delivered from Sinai, followed a severe thunderstorm.

Thunderstorms are not confined to any one locality or season, but can occur and do occur whenever a warm, moist air stream is set into turbulent motion in proximity to a cold, dry current. They are more frequent in summer, reaching their maximum in July and August. The distribution in the United States has been carefully studied by W. H. Alexander and colleagues. There appears to be a seasonal shifting of the centers of activity. There are two well-marked centers in July, one over the Rocky Mountain States and one over Florida. The total number of days with thunderstorms for a period of 20 years (1894–1923) is:

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Average Annual
Boston......	2	2	19	18	43	67	93	76	41	11	2	3	19
New York...	4	4	19	46	79	116	150	113	51	23	4	3	31
Baltimore ...	3	9	29	54	89	131	171	126	55	12	1	4	34
Washington..	5	10	32	65	94	153	187	136	78	17	9	6	40
Tampa	21	31	43	64	184	317	440	430	256	65	11	21	94

Lightning is dramatic and dangerous. There are, however, other forms of electrical dis-

charge in the free air which are beautiful and harmless: the brush discharge or St. Elmo's fire, silent discharge, like the coronal appearances of heavily charged conductors.

And even more beautiful are auroras, which we have good reason to regard as due to an electrification of the upper air strata, practically discharges *in vacuo.* It is now held that auroras are due to bombardment of the upper air strata by cathode rays. Perhaps the most significant research along this line is the work of Vegard, who claims that by subjecting nitrogen at extremely low temperature and in a molecular state to a bombardment of cathode rays, he succeeded in getting in the spectrum lines coinciding with the auroral line, $\lambda = 5577$ Å. American investigators, however, hold that the relation is not yet firmly established. Three distinguished astronomers in our country and the professor of physics at Toronto are inclined to question the evidence. We can do no better than quote from a recent letter from Professor V. M. Slipher of the Lowell Observatory:

> Stronger evidence than I have yet seen of his is required before concluding that the monochromatic green line has yet been produced in the laboratory. Knowing what I do of the Aurora spectrum and the relative be-

CORONA

DIFFRACTION OF LIGHT THROUGH CLOUD

havior of the nitrogen bands and the green line, it would be surprising if it should be found that nitrogen, which is so disposed to radiate bands, should also radiate monochromatically the green line.

Professor Harold D. Babcock of the Mt. Wilson Observatory writes:

As to Vegard's work on solid nitrogen I must say that it appears to me quite inconclusive. I think that much credit is due him for his pioneer work on these spectra but I feel that the quantitative side of his work is rather weak and that he has allowed his ideas on the rôle played by solid nitrogen in our atmosphere to dominate him unduly.

An inspection of McLennan's photographs shows only $\lambda = 5231$ in the phosphorescence spectrum of solid nitrogen and in the luminescence spectrum of very cold nitrogen vapor no line which could possibly be identified with the position $\lambda = 5577$. The diffuse multiple character of the green radiation which has its maximum intensity at $\lambda = 5556$ does not correspond with the extremely sharp single line which appears on my photograph of the persistent auroral light. While it is true that differences in excitation produce marked changes in the character of spectral lines, still the difference in this case is so great that even if the two had approximately the same wave-length there would still be room for doubt as to their common origin. The problem of identifying the green auroral line may still be considered open. I hope to make further measurements of the upper limit of its line width.

The Auroral Green Line

McLennan and Shrum, in the "Proceedings of the Royal Society," Vol. 108, 1925, under date of June 15, 1925, have discussed at length the origin of the Auroral Green Line 5577 Å and other spectra associated with the Aurora Borealis. They conclude that —

1. In studying the effect of large admixtures of helium or of neon on the spectrum of oxygen, a hitherto unknown line has been photographed.

2. The wave-length of this line is 5577.35 ± 0.15 Å. It is very sharp and is subject to great fluctuations in intensity.

3. This line is identical with the auroral green line $\lambda = 5577.350 \pm 0.005$ Å.

4. It must be attributed to some hitherto unknown spectrum of oxygen.

5. Helium has been used to bring out the bands of nitrogen with an intensity distribution similar to that found in the aurora.

6. The possibility of metastable helium acting as the exciting agent on the auroral spectrum has been discussed.

Chapter VI

DROUGHTS, FLOODS AND FORECASTS

THE easiest way of making a drought that I ever read of, is described in the Old Testament, where Elijah the Tishbite, who was very much displeased with the actions of Ahab, King of Israel, finally told the King that unless he made certain changes in his mode of life, not a drop of rain should fall, no, not even a drop of dew should form. This drought, we are told, lasted three years. How the prophet knew in advance that a dry period was about to set in, nobody can conjecture. It may have been just a guess; or old Elijah may have had some basis for this warning or seasonal forecast, if we choose so to regard it. The same stern old prophet, you may remember, made a highly successful daily forecast of coming rain by the simple expedient of sending his man-servant to the roof, who reported to his master the growth of a cloud at first no larger than a man's hand.

But life is somewhat different to-day, and by means of rapid methods of communica-

tion, the weather conditions over a wide area — a continent, an ocean and a hemisphere — are gathered together, plotted and charts drawn, showing the location and development of storm areas, fair-weather areas, cold waves and warm waves, high humidity and low humidity, wind directions with velocities, and clouds or absence of clouds.

In studying the frequency of floods, one is struck by the fact that droughts precede floods. In nearly all cases, a prolonged period of dry weather is ended by unusually heavy rain. The reason is obvious. While there may not have been much water vapor in the air at the beginning, there has been a steady accumulation. When at last the proper conditions of turbulence assert themselves, then a long-stored quantity of vapor can be condensed and copiously precipitated.

If now this first law holds, one might argue that there was a marked dry spell before the deluge. Of this the account in Genesis is silent. We are told only that the people were wicked. But the account of the deluge itself can not be taken too literally, and as it stands is self-contradictory. The waters covered the mountain top, so we are told. Now that giant of the Caucasus, Mount Ararat, is approximately

LOW CUMULUS

5800 meters high. If rain fell steadily for 40 days, a rate of 6 meters per hour, 100 millimeters per minute, would be needed. Compare this rate of fall with the heaviest rains of which we have definite record. At Chicago, August 11, 1923, a heavy rain broke all records. In 80 minutes there was a fall of 58.42 mm., 0.075 mm. per minute. Compare this with 100 mm. Or let us take an actual flood — the heaviest rainfall on record. It occurred at Baguio in the Philippines, July 14–17, 1911. The rain lasted four days; and the total was 2239 mm. (88.15 in.). In one day 1168 mm. (45.99 in.) fell. The greatest rate for any five minutes was 10 mm., or 2 mm. per minute, $\frac{1}{50}$ of the rate required for a steady period of 40 days for the flood in Genesis.

The wettest spot on earth, Cherrapunji, on the south side of the Khasi Hills in East Bengal, gets less than 11 meters in a year. But for Noah's flood we are asked to believe that 14,200 mm. fell per day. On the other hand, the statement that the fall was 15 cubits, a cubit being 560 mm., is more reasonable, and would make the rate of 210 mm. per day correspond with the heaviest 24 hours' rainfall recorded in the United States — at Taylor, Texas, September 9–10, 1921, when after a

prolonged drought 587 mm. (23.11 in.) fell. This is as much rain in one day as London gets normally in a year.

As this Texas record of 24 hours' rainfall is the greatest in our country, let us examine the pressure and air-stream conditions preceding, during and following the flood.

There had been a drought for nearly two months. No storms had traversed the southwest since the 10th of July, nor were there any well-defined anticyclones. The pressure was persistently high over the Gulf and Atlantic Coast States. This brought about a flow of air from the south and east which normally would carry in much water vapor. But the circulation was sluggish and there was little convection and consequent cooling and condensation. The winds were light and, essentially descending, were warmed and dried in their slow descent. They also were flowing into a warmer and drier atmosphere.

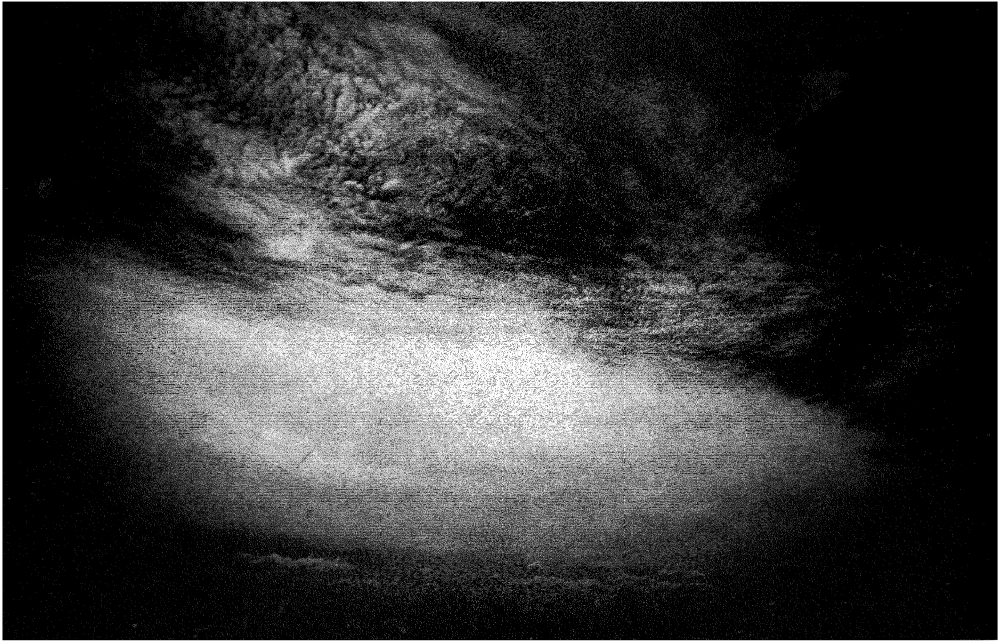
If under such conditions a tropical storm could move from east to west over the Gulf, or on the other hand, a vigorous storm from the Pacific move across the Southwestern States, or even a moderately active low move southward east of the Rocky Mountains, precipitation would have been nearly normal.

None of these happened, however; and there was a steady accumulation of water vapor at high temperature. On the 7th of September, two days before the rain, a hurricane appeared in the extreme West Gulf and moved slowly north about 200 kilometers per day. Although of such feeble intensity as to escape detection at the time by the forecaster, we know now that it moved steadily northward, and was over Central Texas on the 9th. With it came the turbulence needed and the cooling which caused the rain. Unlike most storms, the direction of motion was northward rather than eastward. We have then an indraft of warm, moist air from the southeast underrun on the south side by colder air which originally was a north wind over the Plains States, but curving in its flow 160 degrees. A mass of warm, moist air about one million square kilometers was surrounded by a sector of relatively cold air, shaped like the upper half of a gigantic S.

Furthermore, conditions were favorable for rapid uplift of the mixture of air and vapor. As the pressure decreased there was further expansion and cooling and also an uplift due to topography, as the land rises about one meter per thousand proceeding north, or in the direction of the storm's progress.

The temperature of the northward-flowing warm air was approximately 1100, percentage of saturation 90, weight of water vapor per unit volume 23 grams. This air stream was underrun by a stream from the north, temperature 1040, saturation 60, and weight 6 grams. Under normal conditions the temperature falls about 25 per 100 meters rise. Hence raindrops formed easily and as the storm moved slowly northward 25 kilometers per hour, this mass of vapor, perhaps 1000 kilometers in length, continued to condense and precipitate, the average rate per minute for the whole period being 0.4 mm. For nearly three hours, however, on the evening of the 9th, condensation was most active and the rate was nearly four times greater, that is, 1.5 mm. per minute.

Most of our storms cross the country from west to east but this storm moved northward. We find in nearly all storms a steering line or warm front. This is indicated by clouds changing from cirrus and cirro-stratus to alto-stratus and these in turn to stratus, nimbus and fracto-nimbus. The rear (west) boundary of the warm sector is called the squall line or cold front. On the weather map this is the trough of low pressure. There are two kinds of rain, one in advance of the warm front



CUMULUS–ALTO–STRATUS–AND–CIRRO–CUMULUS

caused by warm air overrunning a bank of cold air before it. The second and later rain sector comes where the warm sector ends. A mass of cold air pushes in under the warm air and as the slope is steeper, generally the rain is heavier but the duration shorter.

Let us now examine the conditions which cause abnormally heavy rain in various parts of the world. During the summer of 1924, in the province of Chihili in Northern China, 63,000 square kilometers (25,000 square miles) of rich agricultural land were flooded and five million people driven from their homes. The water was one meter higher than in the memorable flood of 1917, when three million people were forced from their homes and the damage amounted to $100,000,000. This year in two days during July there was a fall of 240 mm. and in three days at Tientsin 813 mm. fell, that is, at the rate of 0.2 millimeters per minute.

Floods in China are recurrent. While contributing factors are deforestation and lack of adequate storage basins, we must go back to the inflow of moist air from the southeast, which under certain pressure distribution is accentuated. Thus in these flood periods, we find that the North Pacific hyperbar of summer has deepened and moved east, hence a strong southeast monsoon.

Furthermore, let us study the southwest monsoon which determines harvest conditions in India. Now the monsoon itself, to quote Dr. Simpson's words,

> is not the simple result of a single physical condition. It is produced by a combination of circumstances involving consideration of temperature, pressure, humidity, geographical relationships between land and sea, the rotation of the earth and lastly but probably the most important, the distribution of mountain ranges.

There are certain definite air streams moving from the Arabian Sea. These strike the Western Ghats at right angles and are forced upward 1500 meters. As we saw previously with the flood in Texas, conditions all favor rapid condensation. The air streams in question have travelled several thousand kilometers over a warm ocean. There are approximately 25 grams of water vapor for every cubic meter of air. The cooling due to uplift readily causes heavy rain. On the Western Ghats the amount may be 1270 mm. (50 in.) in a month, or 0.03 mm. per minute. A significant factor then is the angle of inclination of the rain-bearing wind to the mountains. When air from the Arabian Sea is deflected to the right and thus becomes a northwest wind instead of southwest, the season is a dry one in

India. This happens when the Indian Ocean hyperbar is shifted south.

Again let us study dry and wet seasons in our country, beginning with the Pacific Coast, more particularly California where so much depends upon departures from a rather limited rainfall. In a dry winter month (winter is the rainy season) the writer has computed a total rainfall for the State of approximately 26 million metric tons (24,000,000 English short tons); in a wet winter month 165 million tons or more than six times as much as in a dry month.

We may confidently predicate three laws governing seasonal rain in California:

I. When the continental hyperbar is displaced to the northwest, the general drift of surface air being from the northeast, the winter will be dry.

II. When the Aleutian infrabar is displaced southward, there is an accelerated flow of southerly surface winds with frequent and heavy rains, and much snow in the Sierra.

III. A dry period in winter in Central and Southern California is due primarily to a retrogression of the Aleutian infrabar. The winds blow parallel to the coast and are moving from colder to warm regions. There is no uplift as in the case of southwest winds which have travelled a long distance over comparatively warm water and therefore carry a load of approximately 22 grams of water vapor per cubic meter.

These laws are found exemplified in the dry winter of 1923–24. Less than half the normal amount of rain fell. The control appears to have been a stagnant hyperbar over Oregon, Nevada, Utah, and Northern California. The winds were from the north and northeast; and the successive surges of polar air only reinforced the existing high pressure.

Finally, a word concerning the now well-known drought in Southern England and Northern France during 1921. The rainfall was only half the normal. The pressure distribution was significant. A ridge of high pressure connected the Atlantic hyperbar with a north polar anticyclone more or less permanent. And of course when there are hyperbars, there are also infrabars somewhere; and in this case these existed over Greenland and Northern Asia. We had then essentially a condition of stagnant or slow-moving anticyclonic air. Under such conditions, east-bound cyclones or disturbances make slow progress eastward and incline northward, seemingly unable to break through the barrier of the "high." Sir Napier Shaw illustrates this by two maps, one of Saturday, November 12, 1921, and another of Friday, November 18, 1921. In like manner, the drought on this side of the Atlantic

in 1924, especially the deficit in rainfall during October and November, can be explained by the persistent anticyclonic condition.

East of the Mississippi River except in Florida, the rainfall for October and November was approximately 150 mm. (6 in.) below the normal. A stagnant hyperbar 1025 kbs. (30.25 in.) over the Eastern half of the United States resulted in light, descending, variable winds. A tropical cyclone October 17–21, which normally would have moved northward along the Coast, gave abundant rain in Florida but none elsewhere in the United States. It caused some of the lowest pressure readings ever known in the western part of Cuba, 931 kbs. (27.50 in.); but it could not move northward. As might be anticipated, the usual succession of "lows" and "highs" across the United States was prevented. Depressions made no headway eastward. On the other hand, the weather was unusually stormy over the Atlantic, the Icelandic infrabar being unusually deep. Thus a balance was maintained.